ASSESSMENT OF PREDOMINANT NOISE SOURCES AND WORKERS EXPOSURE IN DOWNSTREAM OIL AND PETROCHEMICAL INDUSTRIES IN MALAYSIA

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FACULTY OF ENGINEERING
UNIVERSITY OF MALAYA
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ALIFF FIRDAUS BIN MAT YUSOFF

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ABSTRACT

Abundant of publicly available data supports the fact that noise induced hearing loss (NIHL) is one of major threat to workers' health in most industries globally. Similar trending can be observed domestically, where NIHL remains as the most reported occupational health diseases since the last decade.

FMA (Noise exposure) Regulations, 1989 is currently undergoing revision process. The revised noise regulation is expected to be more stringent and putting emphasizes on noise control at the source rather than relying only on hearing protection device to protect workers' hearing. In addition, the regulations will also introduce periodic noise monitoring and more significant penalty will be enforced. As the regulations on noise becoming more stringent, a comprehensive and pragmatic approach need to be adopted by the industry to meet the requirements.

This study aims to provide insight on the current exposure level, compliance status and characterizing noise sources within oil and gas industries. The samples for this study were collected from noise exposure monitoring report of the facilities in the respective business sectors within oil and gas industries, namely upstream, downstream, midstream and petrochemical.

Statistical analysis was performed on parameters used to evaluate workers' exposure and compliance, L_{Aeq8}, L_{max} and L_{peak}. The analysis was performed to characterize the noise exposure level with respect to their business, facilities and their job functions. The mean L_{Aeq8} for oil and gas industries was 76.3 dB(A) (95% CI = 76.3 – 78.0). Therefore, the study concluded that overall oil and gas industries is in compliance with the existing L_{Aeq8} noise limit of 90 dB(A) and revised noise limit of 85 dB(A). However, the study predicted with 95% probability that, 10% of the workers' exposure may still exceed 90 dB(A). The data suggested that upstream business, specifically exploration and

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production facilities, may face challenges in complying to the revised noise exposure limit. Average L_{max} was 107.1 dB(A) (95% CI = 106.3 – 108.0), hence, the oil and gas industries in general was in compliance to L_{max} limit of 115 dB(A). As for exposure to ceiling limit, the mean L_{peak} was 136.3 dB (95% CI = 136.0 – 137.0). All other business categories except for Downstream were in compliance to L_{peak} PEL of 140 dB. AIHA noise exposure control category protocol was adopted to conclude Daily Noise Dose (DND). Approximately 86% of the samples were concluded as Rating 3 (50% - 100% DND) or below, 11% at Rating 4 (> 100% DND) and 3% at Rating 5 (> 500% DND). Upstream business contributed to the highest proportion of working cluster assigned as Rating 4 (61%) or Rating 5 (77%).

Learnings from this study hopefully will provide facilitate the authorities, and industry in the implementation of revised noise regulation. This study recommends that company should consider more robust approach such as adopting Buy-Quiet policy or Quiet-by-Design to eliminate or minimize noise at the source. This will prevent over-reliance on HPD to protect our workers' precious hearing.

Keywords: Noise sources; noise exposure; noise regulations; noise limit; oil and gas

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ABSTRAK

Kehilangan pendengaran akibat bunyi bising merupakan ancaman utama kepada para pekerja di seluruh dunia. Terdapat banyak sumber yang boleh didapati umum bagi menyokong dakwaan tersebut. Perkara yang sama berlaku di negara kita, di mana, kehilangan pendengaran akibat bunyi bising telah mencatatkan jumlah laporan penyakit perkerjaan yang tertinggi sejak sedekad lalu.

Peraturan-peraturan (Pendedahan Bising) di bawah Akta Jentera dan Kilang, 1989, sedang melalui proses semakan semula. Peraturan yang telah disemak semula akan lebih ketat dan penekan akan diberikan terhadap kawalan bunyi bising di sumber, berbanding kebergantungan penuh terhadap alat kawalan pendengaran bagi mengawal pendedahan terhadap bunyi bising. Peraturan-peraturan selepas semakan semula akan mengenalkan pemonitoran bunyi bising berkala dan penalti yang lebih tinggi berbanding sekaran. Industri memerlukan pendekatan yang lebih tuntas dan pragmatik bagi mematuhi peraturan baru yang lebih ketat

Kajian in bertujuan memberikan makluman terhadap kadar pendedahan, status pematuhan dan pengenalpastian sumber bunyi bising di industri minyak dan gas di Malaysia. Sampel bagi tujuan kajian ini diperolehi dari laporan pemonitoran pendedahan bunyi bising di kilang-kilang terbabit di setiap sektor, seperti industi huluan, hiliran, pertengahan dan petrokimia.

Analisis statistik dijalankan ke atas L_{Aeq8}, L_{max} and L_{peak}, parameter bagi menilai pendedahan pekerja and pematuhan. Analysis dijalankan bagi mencirikan tahap pendedahan bunyi bising berdasarkan sector perniagaan, kilang dan jawatan kerja. Purata L_{Aeq8} bagi industri minyak dan gas adalah 76.3 dB(A) (95% CI = 76.3 – 78.0). Kesimpulan yang dibuat adalah, industri minyak dan gas adalah dalam pematuhan kepada takat kebisingan L_{Aeq8} yang dibenarkan, iaitu 90 dB(A) and takat kebisingan selepas

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semakan semula iaitu 85 dB(A). Walaubagaimanapun, kajian ini mengangarkan dengan 95% kebarangkalian, 10% dari keseluruhan pendedahan pekerja akan melebihi takat 90 dB(A). Kajian ini melihat, industri hiliran di bahagian explorasi dan pengeluaran, akan menghadapi masalah dalam pematuhan kepada takat kebisingan yang telah disemak semula. Purata L_{max} adalah 107.1 dB(A) (95% CI = 106.3 – 108.0), disimpulkan secara keseluruhannya, industri minyak dan gas patuh kepada takat L_{max} yang dibenarkan iaitu 115 dB(A). Bagi pendedahan terhadap takat siling, purata bagi L_{peak} ialah 136.3 dB (95% CI = 136.0 – 137.0). Berdasarkan statistic tersebut, semua sektor mematuhi takat L_{peak} yang dibenarkan (140 dB) kecuali industri hiliran. Kesimpulan dos pendedahan kebisingan harian (DND) dibuat berdasarkan *AIHA noise exposure control category*. Keputusan mendapati 86% dari keseluruhan sampel berada di Rating 3 (50% - 100% DND) atau ke bawah, 11% pada Rating 4 (> 100% DND) dan 3% at Rating 5 (> 500% DND). Industri huluan menyumbangkan peratusan tertinggi bagi kluster pekerjaan yang mendapat Rating 4 (15%) dan Rating 5 (5%).

Pengetahuan yang diperolehi dari kajian ini diharap agar dapat membantu pihak-pihak berkuasa dan industry dalam kerja – kerja pematuhan terhadap peraturan baru. Kajian ini mencadangkan syarikat agar menerapkan polisi “Buy-Quiet” atau “Quiet-by-Design” bagi tujuan membanteras atau mengurankan bunyi bising di tempat kerja. Langkah ini diambil bagi mengelakkan kebergantungan terhadap alat perlindugan pendengaran bagi menjaga fungsi pendengaran pekerja.

Keywords: sumber kebisingan; pendedahan bunyi bising; peraturan bunyi bising; takat bunyi bising; minyak dan gas

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LIST OF SYMBOLS AND ABBREVIATIONS

AIHA	:	American Industrial Hygienist Association
ACGIH	:	American Conference of Governmental Industrial Hygienist
BQ	:	Buy-Quiet
dB	:	Decibel
DND	:	Daily Noise Dose
DOSH	:	Department of Occupational Safety and Health Malaysia
E&P	:	Exploration and production
ER	:	Exchange Rate
ETP	:	Economic Transformation Programme
FEED	:	Front end engineering design
FMA, 1967	:	Factories & Machineries Act, 1967 (Malaysia)
FMA, 1989	:	Factory Machinery (Noise Exposure) Regulations 1989
GDP	:	Gross Domestic Product
HCP	:	Hearing Conservation Programme
HPD	:	Hearing protection device
ILO	:	International Labor Organization
ISO	:	International Standard Organization
L_{Aeq8}	:	Equivalent noise exposure level for 8-hour
L_{max}	:	Maximum exposure level
LNG	:	Liquefied Natural Gas
L_{peak}	:	Peak exposure level
LPG	:	Liquefied Petroleum Gas
MEL	:	Maximum exposure limit
MSD		Musculoskeletal Disease

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NADOPOD	:	Notification of Accident, Occupational Diseases and Occupational Poisoning under OSHA, 1994
NCP	:	Noise competent person
NIHL	:	Noise-induced Hearing Loss
NIOSH	:	National Institute of Occupational Safety and Health, US
NKEAs	:	National Key Economic Areas
NRR	:	Noise Reduction Rate
O&G	:	Oil and gas
OSHA, 1994	:	Occupational Safety and Health Act, 1994 (Malaysia)
PDT	:	Pengerang Deepwater Terminal
PEL	:	Permissible Exposure Limit
PEMANDU	:	Performance Management & Delivery Unit
PIPC	:	Pengerang Integrated Petroleum Complex
PTS	:	Permanent Threshold Shift
REL	:	Recommended Exposure Limit
SEG	:	Similar Exposure Group
SLM	:	Sound Level Meter
SPL	:	Sound Pressure Level
STS	:	Standard Threshold Shift
QBD	:	Quiet-By-Design
SoHELP	:	Systematic Occupational Health Enhancement Programme
TWA	:	Time Weighted Average
WHO	:	World Health Organization

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CHAPTER 1: INTRODUCTION

1.1 Introduction

Oil and gas industry begins from the crude oil or natural gas extraction activities or also known as upstream activities. The process followed by the production of refined petroleum products such as gasoline, lubricating oils or greases and other products from the fractionation of crude oil or bituminous minerals such as liquefied petroleum gas (LPG), petrol, aviation turbine fuel, kerosene, lubricating oil, wax fuel oil and bitumen. It also includes the liquefaction and processing of natural gas and treating of condensate or natural gas to produce purified natural gas or liquefied hydrocarbon gases (DOSM, 2000; ISO, 2016).

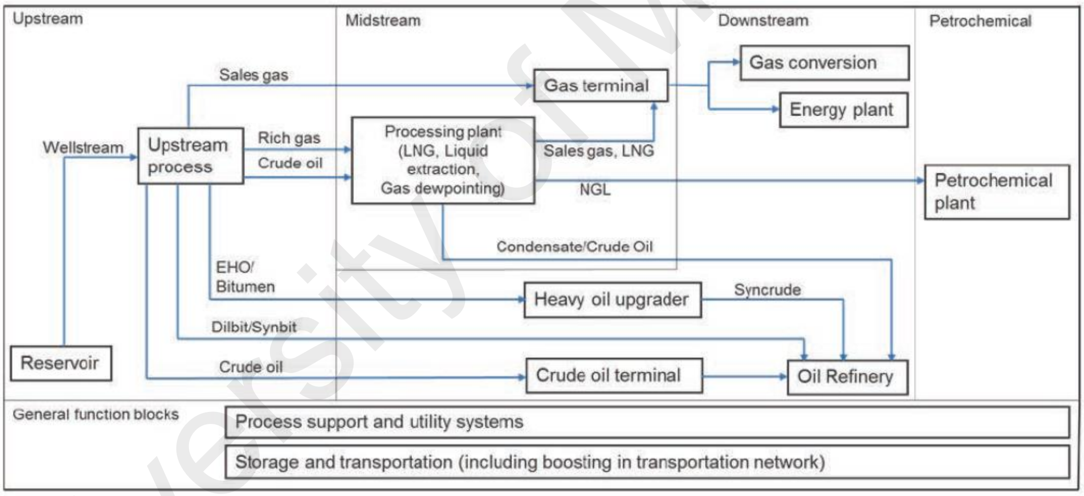

Figure 1.1: Process technology function blocks in the oil and gas value chain (Source: ISO 14224)

Since the past decade, Malaysia's oil and gas industry has been contributing about one-fifth to the national Gross Domestic Product (GDP). As of January 2017, Malaysia is Southeast Asia's second-largest oil producer behind Indonesia with proven oil reserve of 3.6 billion and with estimated production rate of petroleum and other liquid (including crude oil, condensates, natural gas liquids, biofuel and refinery processing gains) reaching 744,000 barrels per day (USEIA, 2017) .

In 2012, Malaysia's Economic Transformation Programme (ETP) under Performance Management & Delivery Unit (PEMANDU), a unit under the Prime Minister's Department reported that oil and gas industry in Malaysia contributes a total of RM 111 billion or 16.6 per cent, to Malaysia's GDP. The portion increases up to 20 per cent GDP in recent years (PricewaterhouseCoopers, 2016). Oil and gas also listed as one of twelve (12) National Key Economic Areas (NKEAs) targeted to generate 3.3 million new jobs by 2020. ETP is targeting five (5) percent annual growth for oil and gas sector until 2020 (Jun, 2016). One of the major projects identified under this programme is the establishment of the Pengerang Integrated Petroleum Complex (PIPC) and Pengerang Deepwater Terminal (PDT) in Johor, a world-class hub for downstream oil and gas activities that is drawing sizeable private investment and is driving our oil and gas capabilities higher up the value chain. PIPC is the single largest downstream/infrastructure investment project in Malaysia, with an expected total investment of RM128 billion. The PIPC project is anticipated to be completed by early 2019 and is expected to employ 70,000 workers during construction and generate 4,000 new jobs upon completion (PEMANDU, 2016).

Focus created on the development and intensification of oil and gas industry in Malaysia attracts over 4000 companies comprising international oil companies, independents, and services and manufacturing companies that support the needs of the industry value chain, both domestically and regionally. Many major global machinery and equipment manufacturers have set up bases in Malaysia to complement local machinery and equipment companies, while other Malaysian oil and gas companies are focused on other segments such as marine, drilling, engineering, fabrication, offshore installation and operations and maintenance (MIDA, 2012).

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Association between exposure to excessive noise level and hearing impairment in oil and gas industry has been well established. The average noise levels in developing countries may be increasing because industrialization is not always accompanied by protection (Marisol Concha-Barrientos, Diarmid Campbell-Lendrum, & Steenland, 2004). Oil and gas industry is gearing towards supporting Malaysia's economy in becoming high-income economy by 2020, the process is expected to add a burden of occupational related diseases such as musculoskeletal disease, noise, and cancer. Impact of industrialization and globalization in adding a burden to nation's occupational health burden has been described in many studies. Worldwide, 16% of the disabling hearing loss in adults is attributed to occupational noise, ranging from 7 to 21% in the various sub-regions. The estimated cost of noise to developed countries ranges from 0.2 to 2% of the GDP where it is the cause of more than one-third of the hearing impairments. The effects of the exposure to occupational noise are higher in the developing regions. (Nandi & Dhatrak, 2008; PEMANDU, 2013).

The workplace contributes significantly to the total dose of daily noise to which a person is subjected. Almost two decades ago, a studied conducted by World Health Organization (WHO) estimated that, Worldwide, 16% of the disabling hearing loss in adults is attributed to occupational noise, ranging from 7% to 21% in the various sub-regions. The effects of the exposure to occupational noise are often larger for males than females in all sub-regions and the effects are much higher in the developing regions. WHO concluded that occupational noise is a significant cause of adult-onset hearing loss. The majority of this NIHL burden can be minimized by the use of engineering controls to reduce the generation of noise at its source (Nelson, Nelson, Concha-Barrientos, & Fingerhut, 2005). In Asia, NIHL is the most prevalent and preventable occupational disease in most Asian countries. Sources of noise in these countries include manufacturing and agriculture industries, exploitation of natural resources, and urban

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traffic. The highest attributable fraction of adult-onset hearing loss resulting from noise exposure in the world comes from Asian countries. NIHL is a serious health problem in Asia, not only because of the number of affected laborers, but also because the majority of Asian countries are still developing economies where access to health services and preventive programmes are limited. Lack of awareness about NIHL among employers, workers, and health care professionals is one of the main barriers for the prevention of NIHL in Asia (Fuente & Hickson, 2011). Therefore, millions of people around the world are exposed to potentially dangerous noise levels and consequently, there is an urgent need for legislation to adequately protect the auditory health of the workers.

Association between exposure to excessive noise and occupational hearing impairment has long been proven by the scientific community. Occupational noise regulations have been adopted by many to prevent NIHL cases and promote hearing conservation programme (HCP) in companies. A lot of studies also conducted to study the efficacy noise exposure limit regulated by the countries in protecting the workers and preventing occupational hearing impairment. Some countries in the past decade proactively revisited and revised their noise related legislation and reduced exposure limit to as low as 82 dB(A) for 8-hour exposure. Comparison made of the legislations, found that there are notable differences among countries within America region (i.e., north America, south America) in the defined values for permissible exposure limit (PEL) and exchange rate. Analysis of data obtained directly from official government website of the respective countries and the International Labor Organization (ILO) database found that the majority of the countries within America region use a PEL of 85 dB(A) with 3-dB exchange rate. Most nations limit impulsive noise exposure to a peak unweighted sound pressure level of 140 dB or dB(C), while a few use slightly lower limits. However, 27% of the countries in the region still have not established regulations with respect to permissible noise levels and exchange rates. (Arenas J. & Suter, 2014). As a comparison, in Malaysia, under

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Factories and Machineries Act 1967 (FMA, 1967), PEL for noise is still 90 dB(A) for eight (8) hours of exposure and peak limit of 140 dB for impulsive noise exposure to an unweighted sound pressure level, which is similar to the previous study.

In Malaysia, statistics from Department of Occupational Safety and Health Malaysia (DOSH) reported, in 2016, a total of 3860 confirmed occupational diseases and poisonings cases have been reported to the Occupational Health Division. Occupational noise-induced hearing disorders (e.g., Noise-induced Hearing Loss (NIHL), Hearing Impairment, and Permanent Standard Threshold Shift) were the most common occupational disease experienced by workers (74.5%) as compared to other diseases (DOSH, 2018).

As Malaysia progressively moving towards becoming developed countries, industrial activities will be intensified in order to achieve the target. With respect to oil and gas industries, as it has been identified as one of the focus areas under NKEA, any changes in current legislations relevant to its business activities will leave a significant impact in term of financial cost as well as operational challenges. Limited insight on the current situation specific to oil and gas industries imposes unnecessary challenges in protecting the workers in general and hearing health specifically. A situational assessment to understand current compliance status and the challenges in complying the noise exposure limit can help to guide policy and focus research on this problem. This is particularly important in light of the fact that policy and practical measures can be used to reduce exposure to occupational noise.

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1.2 Problem statement

Exposure to noise is regulated in Malaysia under Factories and Machineries Act (Noise exposure) regulations 1989 (FMA, 1989). Under Occupational Safety and Health Act, 1994 (OSHA, 1994), it is a general duty of the employee to ensure the workers are protected against health and safety risks arises from the work activities as far as it is practicable (OSHA, 1994). As such, in protecting workers from risk resulted from exposure to occupational noise, employer is required to establish and implement HCP when the workers are exposed to occupational noise. Recently, DOSH communicated during National Systematic Occupational Health Enhancement Programme (SoHELP) convention in 2017, of the upcoming new Noise Exposure regulations that will be under OSH Act 1994 (Che Mat, 2017). Table 1.1 below summarizes the salient points of the new noise exposure regulations in comparison of existing noise regulation under FMA 1974:

Table 1.1: Comparison table between existing noise exposure regulations and new regulations by DOSH

	Factories & Machineries (Noise exposure) Regulations 1989	**Revised Noise exposure Regulations (in draft)**
Act	FMA 1967	OSHA 1994
PEL for 8 hours	90 dB(A)	85 dB(A)
Action Level or daily noise dose equal to 0.5	85 dB(A)	82 dB(A)
Penalty	RM1,000 (applicable to all provisions)	1. RM 50,000 and / or 2 years jailed (Failed to conduct noise assessment) 2. RM 1,000 and / or 3 months jailed (Workers) 3. RM 10,000 and / or 1 year jailed (other provisions)

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As the requirements is getting stringent, the industries need to strengthen existing controls to ensure its readiness to comply or at risk of being penalized. In order to address the new requirements, this study is focusing on identifying significant noise sources (e.g., equipment, process, activities) and evaluating existing noise exposure level in selected oil and gas segment namely upstream – production platform and terminal, downstream refineries as well as petrochemical plants. Then, the study will identify gaps and challenges in meeting the new requirements (i.e., over reliance on HPD) and propose possible interventions to address the issues. The findings from this study hopefully will help industries to prepare with necessary resources as well as for the regulators to strengthen enforcement and supports where it is needed (i.e., Small medium enterprise).

1.3 Objectives

This study aims to:

1) analyze noise exposure data to evaluate industry typical exposure level
2) characterize noise sources (i.e., process, equipment, activities) commonly found in oil and gas industry
3) propose intervention plans to improve controls based on AIHA Noise Exposure Control Category
4) quantify industry challenges to comply to 85 dB(A) from 90 dB(A)

1.4 Benefit of the study

All developments pose a similar challenge; to achieve a balance between operational performance and minimizing adverse impact to the health and safety of the workers. Findings and insights gained from this study are aimed to strengthen the engineering noise controls components of HCP and remove over reliance on hearing protection devices (HPD). The study will help to enhance the understanding on the mechanics of noise generation within oil and gas industries. This study will improve and expedite decision

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making process (e.g., process design, equipment selection, procurement) of the key decision makers in the industries such as project manager, process design engineer, process and maintenance engineer. This is important as we plan to move away from over-reliance on the use of HPD and to adopt advance hearing conservation policy such as Buy-Quiet (BQ) or Quiet-by-Design (QBD) policies throughout all plant lifecycle (design, construction, operation and decommissioning). In addition, data collected will help us to answer the study objectives which can be used later to develop exposure and equipment database hence allowing the establishment of noise exposure profile for each businesses / sub-business and respective work units.

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CHAPTER 2: LITERATURE REVIEW

2.1 Definition of sound

Sound is generated as the molecules within the medium (air, water, solid) go into series of compression and rarefaction where sound is produced as a product of energy loss – energy transfer. Noise is the term used to describe unwanted sound or in occupational setting when the sound pressure level is exceeding the occupational exposure limit (WHO, 2001).

2.2 Physical characteristics sound and its unit of measurement

The characteristic sound can be described by frequency, wavelength, period, amplitude, and speed (Royster, Driscoll, & Layne, 2003). Table 2.1 summarizes the common term and parameters used to describe or measure sounds characteristics:

Table 2.1: Terms and parameters used to describe and measure sound characteristics

Term	Definition and application	Symbol	Unit of measurement
Amplitude	Length between highest and lowest pressure, above and below ambient or atmospheric pressure.	A	meter (m)
Frequency	number of complete cycles per unit time.	f	Hertz (Hz)
Period	Duration to complete one full cycle	T	second (s)
Wavelength	Distance traveled by sound wave during one pressure cycle	λ	meter (m)
Pressure	Force per unit area. Sound pressure usually measured at the worker	P	Pascal (Pa)
Power	Energy radiated from noise source. Sound power is useful to characterize noise sources and to estimate noise pressure at specified distance.	W	Watt (W)

Sound pressure is the fluctuation of pressure and expressed as force per unit area, and the unit is Pascal (Pa). The intensity of the faintest sound a person with sensitive hearing

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can detect is about 10^{-12} watts/m^2. In comparison, the intensity of the sound produced by a rocket at launch is greater than 10^{12} watts/m^2. This extremely large range in values require a reference value, such that an increase of 1.0 represents a ten-fold increase in the ratio, also called a 1.0 Bel increase. The term decibel (dB) is equal to 1/10th of a Bel (10 dB = 1 Bel) and is a dimensionless quantity independent of the system of units used.

2.3 Health effects from exposure to noise

Bernardino Ramazzini studied the effect of noise on hearing during 17th century (Felton, 1997; Franco, 2014). By the turn of 20th century, vast evidences already available to support the association between exposure to excessive noise and hearing impairment has been established among workers in various industries. Result from various case studies confirmed that high prevalence of noise induced hearing loss (NIHL) among industrial workers that exposed to noise exceeding occupational exposure limit (Malchaire & Piette, 1997; Retneswari Masilamani, Abdul Rasib, Azlan Darus, & Ting, 2014; Schneider, Peterson, Hoyle, Ode, & Holder, 1961; Thurston, 2013; Yuen, 2014).

As we lived in the 21st century, there are increasing number of studies that found evidences and association on the interaction between noise exposure and exposure to organic solvents such as benzene, toluene, xylene, styrene, trichloroethylene, carbon disulphide, hexane and butanol, and, heavy metals such as lead, mercury and trimethyltin (ACGIH, 2017). Other studies also reported barotrauma and certain ototoxic drugs such as cisplatin and aminoglycoside antibiotics as significant contributory factors to the increase of hearing loss prevalence among the workers. These factors, in combination with smoking, vibration and stress were found to exacerbate the effect of exposure to occupational noise and increase the risk of NIHL among the workers. Noise affects daily life through audiological effects such as hearing loss and tinnitus, non-audiological physical effects (e.g., cardiovascular), and psychosocial and behavioral effects. (Chang et al., 2011; Kim, 2010; Rosenthal & Alter, 2012; Yuen, 2014). Figure 2.1 was adapted from a study on the impact of environmental and occupational noise in Malaysia published in 2014. It summarizes the auditory and non-auditory health effects resulted from exposure to noise. Many studies had similar agreement on the challenges to isolate the effects of age illness, drug usage, or accident to noise-induced hearing disorders (Hoet & Lison, 2008; Kaufman, LeMasters, Olsen, & Succop, 2005; Shu-Ju Chang, Chiou-Jong Chen, Chih-Hui Lien, & Sung, 2006; Unlu, Kesici, Basturk, Kos, & lmaz, 2014; Vyskocil, Truchon, & Leroux, 2011).

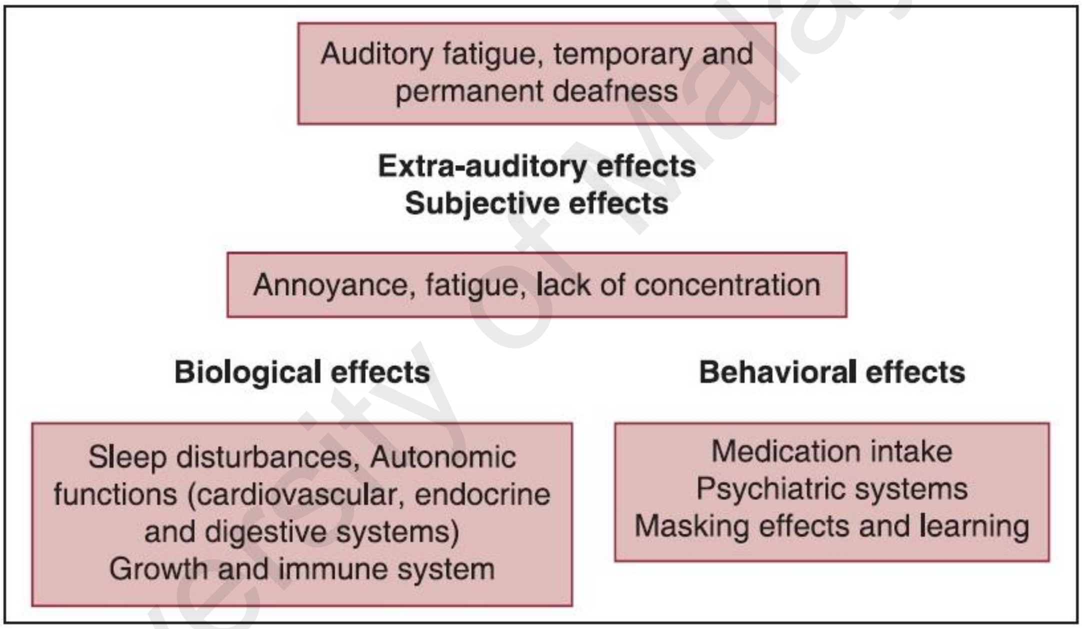

Figure 2.1: Auditory and non – auditory health effects resulted from noise exposure (Source: Yuen, 2014)

2.4 Risk assessment and noise surveys

Noise survey is activity conducted to assess and evaluate the work environment for its potential to NIHL. The general approach in the management of occupational risks at the workplace is to anticipate the hazard, recognize the hazard, evaluate the risk and subsequently to control the hazard or risk (Jahn, Bullock, & Ignacio, 2015). The primary goal is to minimize the risk of hearing loss and other potential health effects resulted from exposure to excessive noise.

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During the noise survey, noise is identified, evaluated and measured with feedback from the workers. Noise sources from the equipment, process or activities will be observed with intend to evaluate their sound level and characteristics. Following the observation and measurement of the noise sources, data need to be evaluated and compared against the regulatory limit or occupational exposure limit published by organizations such as ACGIH. Based on the comparison, the level of risk is determined and in methods of control can be proposed (Driscoll, 2009).

There have been many accepted approaches in conducting noise survey depending on the objectives, situations and resources (Malchaire & Piette, 1997; Royster et al., 2003). WHO in their publication summarized typical process flow in conducting noise survey (WHO, 2001) as shown in Figure 2.2 below.

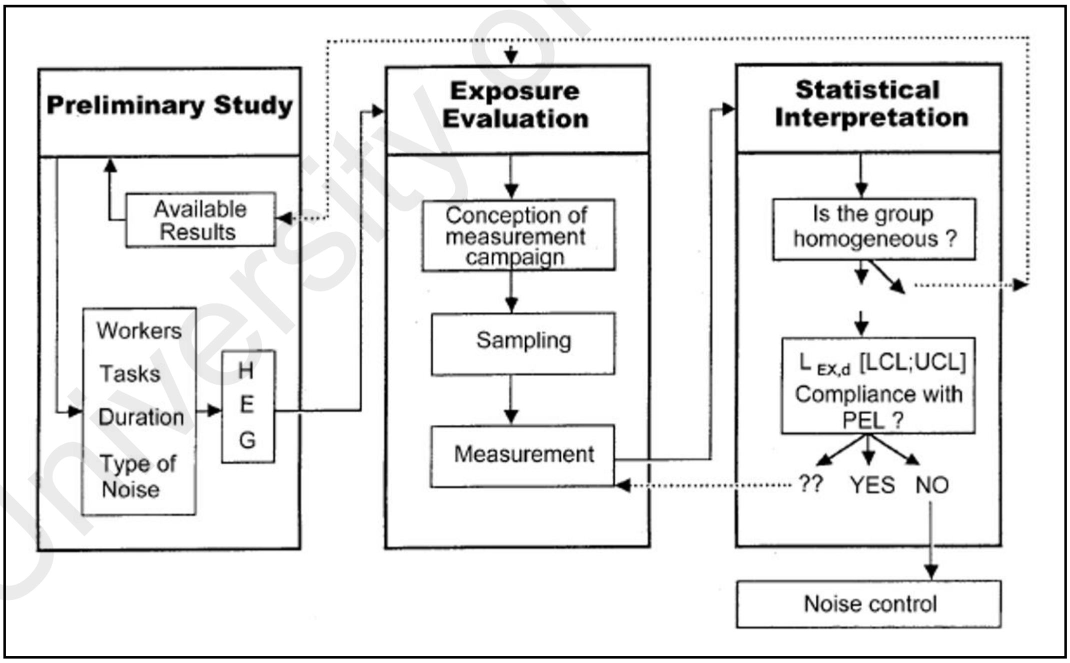

Figure 2.2: Simplified process flow and activities when conducting noise survey (Source: WHO, 2001)

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2.5 Noise exposure criteria and legislation for noise in Malaysia

Workers are one of nation most precious resource and it is critical for a nation to ensure the workers are healthy and productive to contribute to the nation's growth. Within the same context, countries usually have their own sets of regulations specific to protect workers' exposure to excessive noise. Despite the existence of country regulatory limit as listed in Table 2.1, there is no guarantee that compliance will ensure full protection of worker's hearing. This is due to the complexity and diverse variables associated with an individual's susceptibility to the noise exposure as described in Section 2.3.

2.5.1 Background of noise exposure criteria

Studies and work for determining suitable noise exposure limit in working population begun since late 1960s to early 1970s (Arenas J. & Suter, 2014). The initiative was led by ISO and NIOSH. Subsequent from the standard issued by ISO in 1971, NIOSH has published "*Criteria for a Recommended Standard: Occupational Exposure to Noise*" in 1972 (ISO, 1971; NIOSH, 1998). In both standards, the organizations unanimously recommended an 8-hour noise exposure of 85 dB(A) to be the decision criteria, of which hearing conservation measures need to be implemented. The limit was determined after comprehensive review of relevant studies conducted by both organizations estimated that approximately between 10 to 15 percent of workers will be at risk of NIHL if exposed to 85 dB(A) for 8-hour daily over 40-year working lifetime. These criteria are now adopted by most countries outside Europe including Malaysia.

Table 2.2: Comparison of studies conducted on excess risk of hearing impairment at the respective L_{Aeq8}

Organization	Exposure Level (L_{Aeq8})	% Excess Risk of Hearing Impairment
ISO (1975)	90	21
	85	10
	80	0
EPA (1973)	90	22
	85	12
	80	5
NIOSH (1972)	90	29
	85	15
	80	3

Comparison of NIOSH Recommended Exposure Limit (REL) and PEL as regulated under FMA, 1967 in Table 2.3.

Table 2.3: Comparison on the duration to reach 100% DND between NIOSH REL and FMA, 1989 PEL

Duration to reach 100% DND	REL for 8-hour exposure by NIOSH in dB(A)	PEL for 8-hour under FMA, 1989 in dB(A)
8-hour	85	90
4-hour	88	95
2-hour	91	100
1-hour	94	105
30-minute	97	110
15-minute	100	115

2.5.2 Noise Regulations in Malaysia

Noise exposure in Malaysia is regulated under Factories and Machineries Act 1967 (Noise Exposure) Regulations, 1989. The PEL and ER for Malaysia are presented in Table 2.1 along with PEL from other countries for comparison purposes. From the table we can see that a number of countries has adopted PEL below 90 dB(A) as early as 1982. An update to Malaysia's noise exposure regulations was anticipated since 2014. The update to the occupational health and safety requirements for noise shall comprise changes to the exchange rate and noise exposure criteria. At this point of this study

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conducted, however, Malaysia still has not enforced the revised version of Noise Regulations where it is anticipated the PEL for 8-hour exposure to be reduced to 85 dB(A).

Table 2.4: Comparison table of noise PEL and ER of other countries with FMA (Noise Exposure) Regulations, 1984

Country, date of regulation	L_{Aeq8} dB(A)	ER, dB(A)	Action Level, dB(A)	L_{max} dB(A)	L_{peak}, dB(C)
Malaysia, 1984	90	5	85	115	140
Argentina, 2003	85	3	85	110	na
Australia, 2000	85	3	85	na	140
Brazil, 1992	85	5	85	115	130
Canada, 1991	87	3	84	na	na
Chile, 2000	85	3	80	115	140
China, 1985	85	3	85	115	na
Colombia, 1990	85	5	na	na	na
European Union (EU), 2003 & UK, 2005	87	3	80 – 85 & 135 – 137	na	140
Finland, 1982	85	3	na	na	na
France, 1990	85	3	na	na	na
Germany, 1990	85	3	85	na	na
Hong Kong	90	5	85	na	140
India, 1989	90	na	na	na	na
Israel, 1984	85	5	na	na	na
Italy, 1990	85	3	85	na	na
Japan	90	5	na	na	na
Mexico, 2001	85	3	80	na	na
New Zealand, 1995	85	3	85	na	140
Norway, 1982	85	3	80	na	na
Spain, 1989	85	3	80	na	na
Sweden, 1992	85	3	85	na	na
United States, 19837	90	5	85	115	140
Uruguay, 1988	85	3	85	110	na

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2.5.3 Noise exposure in Malaysia

Since the last decade, NIHL remains at the top of WHO occupational risk factors priority list besides musculoskeletal disorder (MSD), skin disease and occupational lung cancer (WHO, 2004). The similar trend was observed in Malaysia, where NIHL remained as the most reported occupational diseases above MSD and occupational lung diseases (Che Mat, 2017; DOSH, 2018).

2.6 Noise types

Characterization of noise is one of critical steps in determining the appropriate control of occupational noise. Information such as process, source and type of noise, noise radiation mechanism is critical in determining noise controls (Dryden S. L. & Judd S. H., 1973). In characterizing noise, it is imperative to have a working definition to ensure consistency during sample measurement as described in Figure 2.3. As such, definition as specified in Factories and Machinery (Noise Exposure) Regulations 1989 will be adopted for the purpose of this study. The type of noise will be defined as follows:

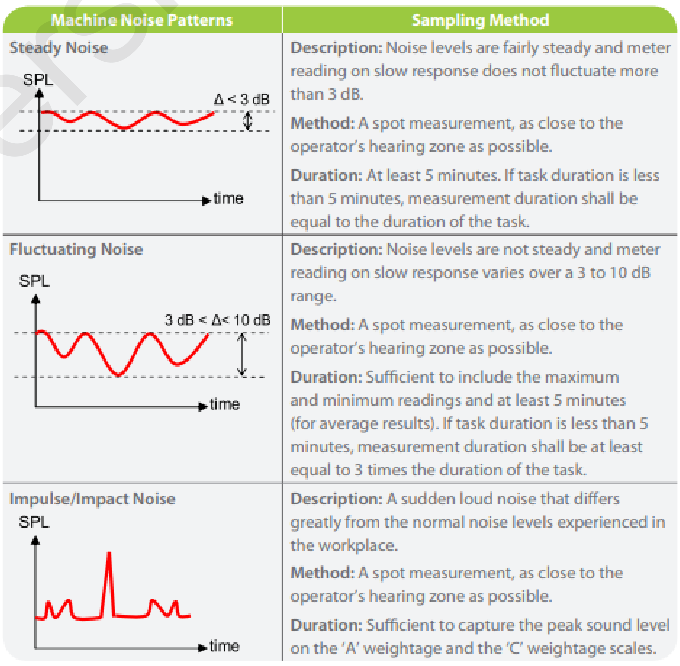

Figure 2.3: Noise type and recommended measurement method (Source: WSH, Singapore, 2014)

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2.7 Instrumentation and measurement of sound

The sound level meter (SLM) is a device used to measure sound pressure levels by electronically sensing the fluctuations in atmospheric pressure and generates an electrical signal. The signal will be filtered via weighting network (e.g., A- or C-weighting) depending on the objective of measurement. The A-weighted sound level, dB(A) is used in regulations and standards since it reflects how humans perceive the loudness of sounds. A-weighted sound level correlates well with hearing-damage risk due to long-term noise exposure. In contrast, the hearing damage risk from short impulsive noise like explosives is measured in C-weighted sound level, dB(C).

Noise dosimeter is essentially a more portable version of SLM which allow measurement of worker's noise exposure over a period of time. Noise dosimeter integrates noise exposure level, based on the configuration of criterion level, exchange rate, and threshold level. Criterion Level (CL) represents the daily limit of accumulated sound energy a person may be exposed to a period of 8-hour (FMA, 1989). For a working shift other than 8-hour, noise dose calculation should be normalized to allow direct comparison of exposure monitoring results to the regulation criteria. Exchange rate (ER) is described in detail in Section 2.7.1. Threshold Level (TL) is the cutoff level, below which the sound energy is omitted from the overall DND calculation. By definition of noise described in FMA 1967 (Noise Exposure) Regulations, TL is set to 80 dB(A).

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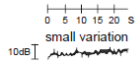
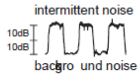
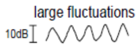
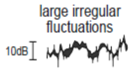
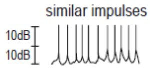
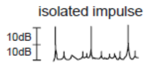
	Characteristics	Type of source	Type of measurement	Type of instrument	Remarks
	Constant continuous noise	Pumps, electric motors, gearboxes, conveyors	Direct reading of A-weighted value	Sound level meter	Octave or 1/3 octave analysis if noise is excessive.
	Constant but intermittent noise	Air compressor, automatic machinery during a work cycle	dB value and exposure time or L_{Aeq}	Sound level meter Integrating sound level meter	Octave or 1/3 octave analysis if noise is excessive.
	Periodically fluctuating noise	Mass production, surface grinding	dB value, L_{Aeq} or noise dose	Sound level meter Integrating sound level meter	Octave or 1/3 octave analysis if noise is excessive.
	Fluctuating non-periodic noise	Manual work, grinding, welding, component assembly	L_{Aeq} or noise dose Statistical analysis	Noise dosimeter Integrating sound level meter	Long term measurement usually required.
	Repeated impulses	Automatic press, pneumatic drill, rivetting	L_{Aeq} or noise dose and "Impulse" noise level Check "peak" value	Impulse sound level meter or SLM with "peak" hold	Difficult to assess. More harmful to hearing than it sounds.
	Single impulse	Hammer blow, material handling, punch press	L_{Aeq} and "peak" value	Impulse sound level meter or SLM with "peak" hold	Difficult to assess. Very harmful to hearing.

Noise characteristics classified according to the way they vary with time. Constant noise remains within 5 dB for a long time. Constant noise which starts and stops is called intermittent. Fluctuating noise varies significantly but has a constant long term average ($L_{Aeq,T}$). Impulse noise lasts for less than one second.

Figure 2.4: Measurement approach and type of instrument with respect to type of sound to measure (Source: WHO, 2011)

2.7.1 Exchange rate

Exchange rate is a concept where the energy of the sound pressure is increased or decreased by a factor of two (2). Hence, energy at exposure of 90 dB(A) for eight (8) hours is equivalent to an exposure of 93 dB(A) for four (4) hours. This relationship is described as the equal-energy hypothesis (Starck, Toppila, & Pyykko, 2003). Equivalent noise exposure level for 8-hour (L_{Aeq8}) measure is used to evaluate the potential of noise-induced hearing loss and the action levels at which control measures such as HCP, engineering control and issuance of HPD, must be taken to prevent or minimize possibility of hearing loss when exposed to the limit (Snow, 1999).

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2.7.2 Daily noise dose (DND)

Similar to US noise regulations, FMA (Noise exposure) Regulations 1989 adopts the concept of DND as exposure unit. The concept helps to explain how the individual noise exposures for the various tasks contribute to the overall daily noise exposure. The method below describes the mathematical basis but it was more common to use a chart for the determination of the partial and full noise doses.

$$D = 100\ (\frac{C_1}{T_1} + \frac{C_2}{T_2} + \cdots + \frac{C_n}{T_n})$$

Where:

C_n = Total time of exposure at a certain noise level

T_n = Reference duration for that level as given in the appropriate regulations (e.g., FMA, 1967)

2.8 Sources of machine noise

Machinery noise is created for the most part by mechanical impacts, high-velocity air, high-velocity fluid flow, vibrating surface areas of a machine, and quite often by vibrations of the product being manufactured (Bies & Hansen, 2009). Understanding the mechanics of noise generation is critical in designing engineering controls or selection of equipment. The success rate in the implementation of engineering noise controls is proven higher if noise related aspects were given duly consideration earlier during the design stage such as equipment selection, noise control and plant layout (Driscoll, 2009).

2.9 Principal of noise controls

Noise control is determined generally based on the type of noise produces, at the location where the noise is generated in relation to the receiver (Sutter, 2011). The hierarchy of control with respect to preventing exposure to excessive noise can be described as follows;

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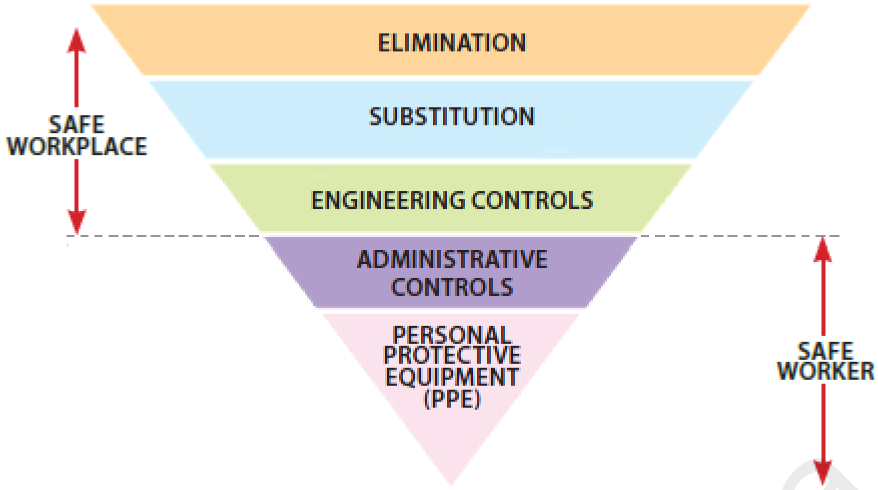

Figure 2.5: Hierarchy of noise controls (Source: WSH, Singapore, 2014)

2.9.1 Noise elimination or reduction at source

The three primary areas for controlling noise from the source are proper design, proper equipment operation, and equipment maintenance. In that regards, the first step in the noise control process should be focusing on noise source treatment because it is directly addressing the cause of a noise problem; the mechanism where noise is produced in the process. In those situations, where there are multiple sources within a machine and the objective is to treat the source, it will be necessary to address all noise-generating mechanisms on a component-by-component basis. As specifically for excessive noise generated by mechanical impacts, the control options available may include methods to reduce the driving force, reduce the distance between components, balance rotating equipment and install vibration isolation fittings. As regards to noise generated from high-velocity air flow or fluid flow, the primary modification is to reduce the velocity of the medium; by either increasing the cross sectional area of the pipeline or reducing the velocity can be reduced by the cross sectional area of the pipeline in question as well as eliminating obstructions in the pipeline to reduce pressure variations and turbulence in the medium being transported. Finally, installation of a properly sized silencer or muffler can provide a significant reduction in the overall noise.

Another common issues to address with is vibrating surface. When the areas of a machine act as a sounding board for airborne noise, the control available include a reduction in the driving force associated with the noise, creation of smaller sections out of larger surface areas, perforation of the surface, increasing the substrate stiffness or mass, and application of damping material or vibration isolation fittings. Another noise control measure to investigate would be to reduce the impact force between the machine and product, between parts of the product itself, or between separate product items.

2.9.2 Isolation of noise source and surface treatment at transmission path

Often process or equipment redesign and source modification may prove to be impractical to implement. There are situations when it is virtually impossible to identify the root cause of the noise. As such, the use of control measures for treatment of the sound transmission path would be an effective means for reducing the overall noise level. The two primary abatement measures for path treatments are acoustical enclosures and barriers. Noise pathways are direct and indirect. Direct paths are from the source to the receiver. Indirect paths are noise reflected from the floor, walls, ceiling and other surfaces in the workplace. Enclosures around the source interrupt the direct noise path.

2.9.3 Hearing conservation programme at receiver

There is little opportunity for noise control at the receiver except for hearing protection, isolation booths, or control rooms. Hearing protection, isolation booths and control rooms are considered treatment of the transmission path.

Administrative controls limiting the receivers time in noisy areas is a method of reducing the worker's noise exposure. Automating process control allows worker to spend more time in a quiet control room rather than a noisy process area. Isolation booths can provide a refuge in noisy areas where the worker presence is required in the process

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area. Noise from indirect paths can be reduced by using less reflective surfaces and by the addition of sound absorbing barriers in the workplace.

2.10 Noise engineering control approach

Establishment of HCP is the most common measures adopted by companies in Malaysia, and it is heavily driven by the requirement stipulated under FMA (Retneswari Masilamani et al., 2014; Tahir, Aljunid, & Hashim, 2014; Yuen, 2014). However, the caveats with relying only on HCP to protect our workers from excessive noise exposure are the lacking in the comprehensiveness of implementation as well as enforcement of the compliance to the requirements. Insufficient or limited resources allocated by the company in HCP add another hurdle to its successful implementation. Furthermore, the situation is exacerbated by the external factors such as lack of trained occupational health doctor and hearing health care professionals, the absence of awareness to the chronic auditory effects induced by noise, and the low educational level of laborers. (Fuente & Hickson, 2011). Hence, HCP it is still not an adequate substitution for engineering controls.

Noise engineering controls is defined by the Factory and Machinery (Noise Exposure) Regulations as the reduction of the noise level reaching the ear-drums of an employee by lessening the amount of noise transmitted to the employee's ear-drums or the amount of noise level produced, but does not include a reduction obtained by the use of a hearing protection device (FMA, 1989).

Noise exposure is normally taken into account during the Front End Engineering Design (FEED) stages in order to gauge and prevent any potential problems during both construction and operational stages. However, ensuring noise exposure impacts are controlled during the FEED stages is secondary to achieving operational requirements,

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due to the fast track nature of energy and oil and gas related projects and the correlation between the growth of oil and gas industry and economic performance.

The first step in determining noise engineering control is to establish acceptable noise criteria for construction of a new plant, expansion of an existing facility and purchase of new equipment. The criteria but must be based on the principle of achieving the lowest reasonably practicable levels of noise exposure. After the criteria has been established, next course of action will depend very much on particular work activities and processes. In general, the actions should be developed from the following considerations:

1) Availability of alternative processes, equipment and/or working methods;
2) Design and layout of workplaces, work stations and rest facilities;
3) Identification of dominant noise sources and application of noise control measures where this is practicable;
4) Taking noise into account when selecting/procuring tools and machinery, i.e. BQ / QBD policy and select lower noise options when these are available;
5) Maintenance of existing equipment, including any installed noise control, in accordance with manufacturer's recommendations;
6) Limitation of the duration and intensity of exposure to noise;
7) Appropriate work schedules with adequate rest periods; and
8) Provision of suitable and sufficient information and training for workers.

2.11 Administrative noise controls

Administrative noise controls require active participation from the employer and employee to effectively minimize exposure or prevent it from exceeding the limit (Nelson et al., 2005). The challenges the implementation of administrative controls are, its requires significant training and cooperation of both workers and management to insure

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work schedules are followed, equipment is maintained in good working order, and purchase specifications are enforced accordingly (Tahir et al., 2014). A proper standard working procedure or company policy is instrumental to complement the programme hence, overcoming the challenges in the implementation.

The critical factor when evaluating the feasibility of implementing administrative noise controls, is to assess the amount of potential reduction in worker's exposure that can be effectively achieved. All constraints need to be examined to determine whether or not administrative noise control measures are practicable. The following section discussed the common administrative controls at the workplace and consideration in the implementation process.

2.11.1 Changes to employee work routine

Changing employee work routines is one way to affect noise exposure. Rotating two or more workers through a job activity with high-noise levels actually distributes the daily exposure among the participants. However, rotating workers in this manner will at least double the number of workers exposed to the sources of concern, and this procedure should only be implemented if the resultant noise exposures for the affected workers are still at safe or acceptable levels.

Professional judgment is required when designing a job-rotation schedule. It is important to ensure that no additional workers be added to the HCP, or the affected workers presently exposed to noise do not have their noise exposure raised to levels where hearing protection is rendered potentially ineffective.

2.11.2 Planning the layout of the work area

Noise control by location of the noise source should be considered for the design and equipment layout of new plant areas and for reconfiguration of existing production areas.

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A simple rule to follow is to keep machines, processes, and work areas of approximately equal noise level together; and separate particularly noisy and particularly quiet areas by buffer zones having intermediate noise levels. In addition, a single noisy machine should not be placed in a relatively quiet, populated area. Reasonable attention to equipment layout from an acoustical point of view will not eliminate all noise problems, but it will help minimize the overall background noise level and provide more favorable working conditions.

Besides grouping equipment by like noise levels, the space density of machines is also an important factor to consider. As sound waves spread outward from a noise source, the sound level decreases with increasing distance from the source, unless the room is total diffuse or reverberant. Therefore, the closer machines are placed together, the greater the opportunity for the buildup of sound energy due to multiple sources.

Workers' exposure is higher as they are closer to the noise source. In ensuring the effectiveness noise control measures, it is important to evaluate the interrelationship between the noise sources and the workers. One good example exhibited in factories where large compressors are grouped together in a room and isolated from any workers. Noise levels in these unmanned compressor rooms can range from 95 to 105 dB(A). Workers only expose briefly to compressor noise during the maintenance or when operating personnel performing routine walkabout in the compressor room (Bies & Hansen, 2009).

Another example can be seen in manufacturing plants. Specifically, when workers service or operate production equipment, perhaps tending to a number of stations up and down a manufacturing line, they will often walk or move along the line approximately one meter away from the equipment. When checking details, the person may be very close to the machine and hence exposed to much higher noise levels. By carefully planning the

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work area, the machinery location and the controls to high noise exposure can be more effective.

2.11.3 Isolation of noise sources

The concept here is to provide relief from sound levels at or above 80 dB(A) through the use of "quiet" areas for workers hence reducing their DND.

Control rooms or noise isolation booths, are another means to provide relief from noise. However, the job needs to be one that will permit, or can be restructured to allow, the worker to spend a significant portion their workday inside a control room. It is common for the ambient sound level inside acoustical control rooms to range from 50 to 75 dB(A), which is low enough to provide sufficient relief from factory noise. There are various options available to employers for increasing the time a worker can spend in a control room. For example, putting equipment controls and gauges inside the room, using automation or computer-based systems, providing remote monitoring via video cameras, can easily increase the time workers can effectively spend inside the control room.

2.11.4 Preventive maintenance of equipment

Equipment will often generate increased sound levels when it is in need of adjustment, alignment or repair. Therefore, maintaining all equipment at its optimum performance condition should be the first step in any noise control programmes. Complimentary to general equipment maintenance, which intended to improves the performance and life-span of equipment, an acoustical maintenance programme will ensure the equipment remains within the noise limits specified by the company, or at the limit the equipment is expected to generate under optimum conditions.

Successful implementation of an acoustical maintenance programme will ensure the correction of simple and often overlooked noise problems. This process alone will yield

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significant benefits in both the long-term life of the equipment and minimizing the noise exposure risk to workers.

2.11.5 Buy-quiet policy

It is a common practice within the industries to have written specifications to define requirements, including noise criteria, for equipment procurement, installation, and acceptance. Within the United States, ANSI has published a standard to guide company preparing for internal company noise specification (ANSI, 2013). In addition, this standard provides direction for obtaining sound level data from equipment manufacturers. Once obtained from the manufacturer, the data may then be used by plant designers while planning equipment layouts. Because of the various types of distinctive equipment and tools for which this standard has been prepared, there is no single survey protocol appropriate for the measurement of sound level data by manufacturers. As a result, this standard contains reference information on the appropriate sound measurement procedure for testing a variety of stationary equipment types. These survey procedures were prepared by the appropriate trade or professional organization in the United States responsible for a particular type or class of equipment.

The first step in the programme is to establish acceptable noise criteria for construction of a new plant, expansion of an existing facility, and purchase of new equipment. The criteria must be effectively communicated and understand by the purchaser and the vendors. This shall follow by enforcement and periodic assurance programme to identify gaps for future improvement.

The earlier in the design process that consideration is given to the noise-related aspects of a project or equipment purchase, the greater the probability of success. Knowledge of the noise characteristics of the various equipment alternatives will allow the buyer to specify the quieter ones.

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Besides selection of the equipment, consideration of noise early in the equipment layout design is essential. The layout designer should exercise caution and take into account the additive effect of multiple noise sources within a room.

Validation of noise criteria requires a cooperative effort between company personnel from departments such as engineering, purchasing, industrial hygiene, environmental, safety, and legal. Involvement from all these parties should begin with the inception of the project and continue through funding requests, planning, design, bidding, installation, acceptance, and commissioning.

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CHAPTER 3: METHODOLOGY

3.1 Scope of study

This study is focusing on oil and gas industries in Malaysia. Data gathered for the purpose of this study was collected from domestic upstream exploration and production, midstream, downstream and petrochemical businesses. Selection of facilities from each business were aimed to ensure the samples size were sufficiently representing of each of the businesses category.

3.2 Data collection

Prior to data collection exercise, some inclusion criteria for the noise exposure monitoring report were set to ensure standardization in sampling approach as well as the reliability and quality of data reported. Data was only extracted from reports that met the criteria. Any reports that did not meet the criteria were excluded from the study. The followings were the inclusion criteria set for this study;

1) The sampling strategy and noise exposure monitoring must be conducted according to recognize method.
2) Instrument used for the monitoring must be calibrated and the calibration certificate for the instrument to be included in the report.
3) The report must include printed instrument log records and noise calculation sheet to enable verification of the monitoring data during the analysis when required.
4) The report must be prepared by Noise Competent Person registered with DOSH.
5) If the facilities conducted several noise exposure monitoring campaigns, only data the most recent noise exposure monitoring report (Additional or Initial) for each facility were included.

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3.3 Data preparation

After collections of noise exposure monitoring report from the identified facilities, each reports were reviewed to verify sampling method, instrument setting and formula used for the calculations of sound pressure level (SPL). This is to ensure the accuracy and validity of the value stated in the report (e.g., sound pressure level, daily noise dose etc.). The data was then extracted from the reports and prepared for analysis using Microsoft Excel® spreadsheet software. List of data extracted from personal exposure monitoring records were as follows:

1) Report general information
    - Facilities name
    - Year of monitoring
    - Type of monitoring (e.g., Additional, Initial)
    - Noise competent person
    - Company

2) Noise dosimeter setting
    - Dosimeter brand & model
    - Frequency Weighting
    - Time weighting
    - Range
    - Exchange Rate
    - Threshold
    - Criterion

3) Monitoring information
    - Working area
    - Work Unit

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- Name
- Shift pattern
- Hearing protection device (HPD) type
- Noise reduction rate (NRR)

4) Monitoring data from dosimeter
    - Final calibration
    - Start and End-time
    - Pause time
    - Duration (minute)

5) Monitoring results
    - Peak Level, L_{peak}
    - Max Level, L_{max}
    - TWA, L_{Aeq8}
    - Daily Noise Dose
    - Exposure Level after HPD

Any corrections identified during the review process were incorporated in the spreadsheet prior to analysis.

A structure based on ISO 14224 were adopted for classification of business, installation and equipment. The classification process is important to ensure consistency in classification as well as to support future communication of findings and insight gained from this study across the companies and locations.

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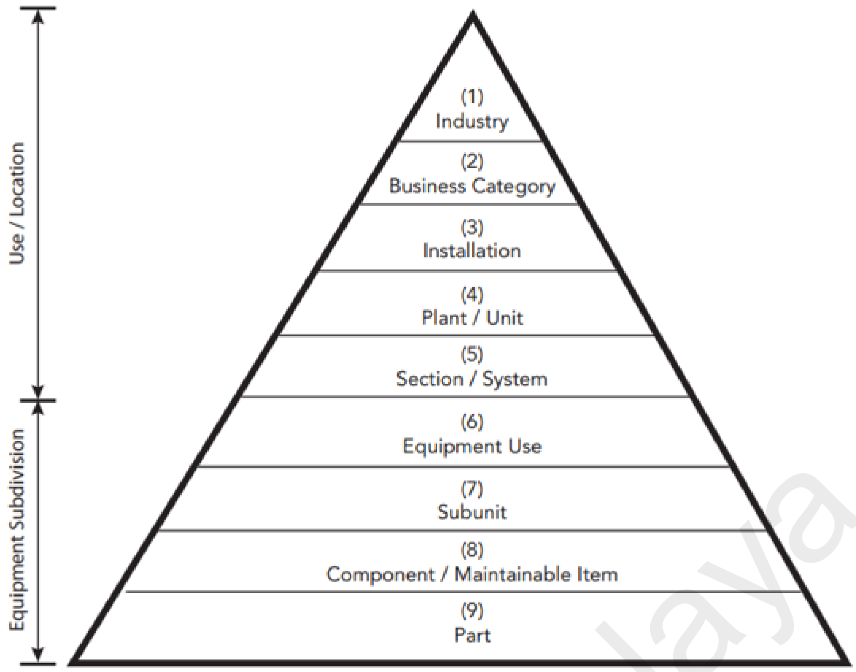

Figure 3.1: Classification taxonomy adopted from ISO 14224

After the consolidation of data from noise exposure monitoring reports, there were 93 different job titles assigned to samples. Job titles were categorized into 15 work cluster based on the convention in Table 3.1 in order to facilitate analysis of the data. In summary, job titles were clustered based on shift pattern, job function, job title and job status.

Table 3.1: Convention to cluster job titles from various noise exposure monitoring reports

Shift pattern	Job function	Job title / job status
Normal (norm)	Production (Prod)	Supervisor (Supv)
Shift	Operation (Op)	Technician (Tech)
Offshore (offs)	Maintenance (Maint)	Contractor (Cons)
	Laboratory (Lab)	Others
	Auxiliary (Aux)	Support

3.4 Data processing

Processing of data extracted from the report were performed using Microsoft Excel® before performing statistical analysis using ProUCL 5.1.002 software. The processing intended to provide structure to the raw data and standardize exposure monitoring results

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that were taken using different dosimeter setting such as exchange rate and criterion. Standardization of exposure monitoring results was critical as some of the monitoring activities was conducted with different instrument setting or sampling duration (i.e., 90 dB(A) vs. 85 dB(A) criterion, 5 dB vs. 3 dB exchange rate (ER) and 12-hour vs. 8-hour sampling duration). The followings are list of formula used and variables:

1) Verification of TWA calculation in the report based on the respective working hours (e.g., 8- or 12-hour shift). The calculation was done by manipulation of the following formula:

   a) TWA equivalent calculated from percent dose for measurement using 90 dB(A) as criterion with 5 dB exchange rate:

$$TWA = 90 + 16.61 \log(\frac{\%D}{100})$$

   b) TWA equivalent calculated from percent dose for measurement using 85 dB(A) as criterion with 3 dB exchange rate:

$$TWA = 85 + 10 \log(\frac{\%D}{100})$$

Where:

TWA = equivalent time weighted average noise exposure, dB(A)
%D = noise dose expressed as a percent

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2) Standardization for criterion, exchange rate or sampling duration when required were done by manipulating the following formula:

$$TWA = Criterion + k\log\left(\frac{\%D}{12.5\,t}\right), k = \frac{ER}{\log 2}$$

Where:

TWA	=	equivalent time weighted average noise exposure, dB(A)
Criterion	=	Exposure limit to be compared against in DND calculation
k	=	modifier
%D	=	noise dose expressed as a percent
t	=	Sampling duration
ER	=	Exchange rate

3) Classification for the DND was based on AIHA noise exposure control category (Royster et al., 2003).

Table 3.2: Noise exposure control categories based on AIHA strategy for assessing and managing occupational exposures, 5th edition

TWA8 and Noise Dose	*SEG Exposure Control Category***	*Applicable Management/ Controls*
<56.8 dBA <1%	**0** (<1% of OEL)	Hearing loss prevention awareness training optional
56.8–73.4dBA 11-10%	**1** (<10% of OEL)	Hearing loss prevention awareness training optional
73.4–85 dBA 10-50%	**2** (10–50% of OEL)	+ Hearing loss prevention awareness training, periodic exposure monitoring
85–90 dBA 50-100%	**3** (50–100% of OEL)	+Hearing Conservation Program inclusion, exposure monitoring, medical surveillance, PPE requirements begin, consider hierarchy of controls
90–101.6dBA 100-500%	**4** (>100% of OEL)	+Implement hierarchy of controls, implement engineering controls
>101.65dBA >500%	**5** (Multiples of OEL)	+ Implement hierarchy of controls, validation of hearing protection sufficiency, dual HPD, priority engineering control

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3.5 Data analysis approach and tools

Statistical analysis approached was adopted from on AIHA Noise Manual 5th Edition (Royster et al., 2003). Most statistical calculations were performed on ProUCL 5.1.002, a software developed by United States Environmental Protection Agency (U.S. EPA) (Singh & Maichle, 2015). All the analyses were done using parametric approach and assuming normal distribution as the samples acquired for the study were large enough (Lumley, Diehr, and, & Chen, 2002).

3.5.1 Statistical parameters

The followings are statistical parameters of interest when analyzing the data collected from noise exposure report.

1) Confidence Interval – Setting a confidence interval around the sample mean provides a range of values within which the true population mean is expected to lie. Usually the 95% confidence internal is used. In other words, only 5% chances the calculated interval fails to include true population mean. Compliance decisions were also determined based on confidence interval (i.e., UCL, LCL)
2) Tolerance limit – Tolerance limit indicates a level below which TWA is expected to fall at a given probability. For an example, 90% tolerance limit indicates the level below which there is 90% probability that the exposure will fall below the limit.

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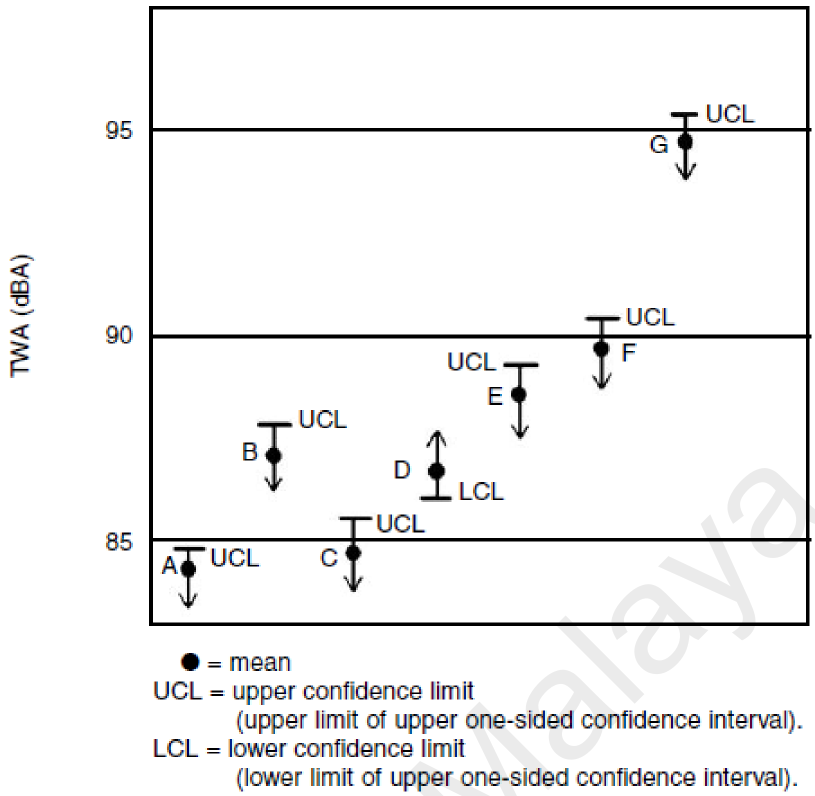

Figure 3.2: Compliance decision based on one-sided confidence intervals to respective criterion levels (Source: NIOSH, 1977)

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CHAPTER 4: RESULTS AND DISCUSSION

4.1 Overview

The study analyzed noise exposure monitoring collected from the respective facilities as listed in Table 4.1. Facilities from upstream business includes E&P production platform and onshore O&G terminal. LNG plant was the only representative from midstream business selected for this study. Downstream businesses were represented by refineries and energy plant. Finally, seven (7) facilities were selected to represent petrochemical business.

Table 4.1 summarizes the number of samples from personal noise exposure monitoring from each business category participated in this study.

Table 4.1: Number samples from personal noise exposure monitoring by facilities by business categories

Business category	Installation category	No. of facilities	No. of samples	samples proportion (%)
Upstream	Production platform	20	274	25
	Terminal	6	194	18
Midstream	LNG	1	174	16
Downstream	Refinery	2	172	18
	Energy plant	2	24	2
Petrochemical	Petrochemical complex	7	256	24
	Grand Total	33	1102	100

This study also included data from area noise exposure monitoring in order to identify and prioritize noise sources that commonly present within oil and gas industries. Table 4.2 summarizes the type of noise sources present within the respective business categories.

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Table 4.2: Number of noise sources samples from area noise monitoring by business categories

Business category	Installation category (No. of facilities)	Type of noise sources			
		Equipment	**Process**	**Activities**	**Area (General)**
Upstream	Production platform (0)	-	-	-	-
	Terminal (0)	-	-	-	-
Midstream	LNG (1)	34	-	-	2
Downstream	Refinery (1)	10	17	-	-
	Energy plant (1)	-	-	-	-
Petrochemical	Petrochemical complex (7)	516	129	4	327
	Grand Total	560	146	4	329

4.2 Results and analysis of equivalent personal noise exposure level (L_{Aeq8}) for oil and gas industries

Analysis of personal noise exposure level (L_{Aeq8}) of samples from all business categories estimated that, the equivalent personal noise exposure level standardized for 8-hour exposure (L_{Aeq8}) was between 76.3 dB(A) and 77.6 dB(A) at 95% confidence level. Figure 4.1 shows the cumulative distribution of equivalent personal noise exposure level (L_{Aeq8}).

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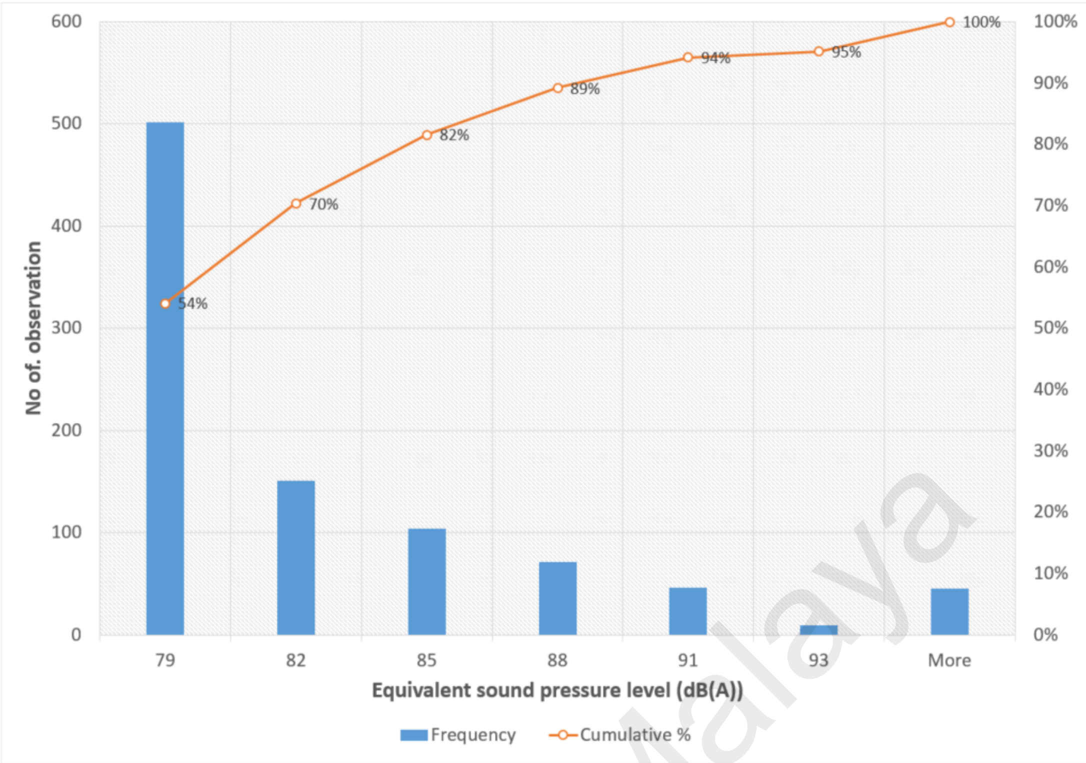

Figure 4.1: Cumulative distribution of equivalent sound pressure level (L_{Aeq8})

Analysis of one – sided upper confidence interval (UCL) to estimate with 95% confidence level of population mean based on the sample mean, concludes that mean of L_{Aeq8} for the worker population to be less than 77.5 dB(A). However, when adjusted for the uncertainty associated with sample size, one – sided tolerance limit (UTL) calculation estimated that there was a 95% probability that 90% of the workers L_{Aeq8}will fall below 95.1 dB(A). The remaining 10% of the worker's population was estimated to be exposed at L_{Aeq8} higher than 95.1 dB dB(A).

Further studies of the noise exposure patterns of workers were able to show that the most significant exposure periods generally arose from occasional exposures at high levels, arising either from intermittent plant characteristics or from intermittent plant visits, rather than from steady exposures. The low L_{Aeq8} average was due to the fact that workers did not constantly working or present at noisy area for the whole work period.

Using the personal exposure samples data, we were able to predict the percentage of population mean above the criterion (i.e., OEL of interest) using the procedure as described by AIHA in their publication, The Noise Manual 5th Edition. From the calculation, it was estimated over 22 % of the worker population will be exposed to L_{Aeq8} of 85 dB(A) or higher, of which 12% of the worker population with L_{Aeq8} 85 - 90 dB(A) and over 10% of the population will expose to L_{Aeq8} of 90 dB(A) or higher. The remaining 78% of the worker population is estimated to fall below 85 dB(A).

In general, the overall L_{Aeq8} of oil and gas industries are lower when compared to average manufacturing industries based on studies conducted between 2012 and 2013. The study reported that L_{Aeq8} of occupational noise exposure among industries were 28% for 91-140 dB(A) and 72% for 86-90 dB(A). Occupational noise-exposed workers were observed to be the highest in the metal industry, followed by textile and food manufacturing. The percentage of workers exposed ranged from 13.6% to as high as 68.9% in each industry. In addition, 103,673 (39%) from total employment of 267,964 were estimated to be workers exposed to high risk noise (Tahir et al., 2014).

4.2.1 Personal noise exposure level (L_{Aeq8}) by business categories

Analysis performed on Upstream, the observations of L_{Aeq8} had an average of 79.0 dB(A) (*SD* = 12.0, SE_M = 0.5, Min = 6.0, Max = 117.0). For Downstream, the observations of L_{Aeq8} had an average of 75.0 dB(A) (*SD* = 8.1, SE_M = 0.6, Min = 43.3, Max = 92.0). For Midstream, the observations of L_{Aeq8} had an average of 72.0 (*SD* = 9.0, SE_M = 0.7, Min= 54.0, Max = 104.0). For Petrochemical, the observations of L_{Aeq8} had an average of 76.0 (*SD* = 9.0, SE_M = 0.5, Min = 39.2, Max = 97.4). Summary of descriptive and compliance statistics for each business category as tabulated in Table 4.3 and Table 4.4 respectively.

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Table 4.3: Descriptive statistics of personal noise exposure level (L_{Aeq8}) by business categories

Business category	N	Min dB(A)	Max dB(A)	Mean dB(A)	SD	50th %-ile	95th %-ile	SE_M
Upstream	468	6.0	117	79.0	12.0	80	96.4	0.5
Midstream	174	54.0	104.0	72.0	9.0	72.7	84.4	0.7
Downstream	196	43.3	92.0	75.0	8.1	75.1	85.3	0.6
Petrochemical	256	39.2	97.4	76.0	9.0	76.6	88.2	0.5

Table 4.4: Compliance statistics of personal noise exposure level (L_{Aeq8}) by business categories

Business category	N	Mean dB(A)	SD	95% LCL	95% UCL	95% UTL
Upstream	468	79.0	12.0	77.8	80.0	94.3
Midstream	174	72.0	9.0	71.0	73.3	85.0
Downstream	196	75.0	8.1	73.4	75.5	85.0
Petrochemical	256	76.0	9.0	75.0	77.0	87.0

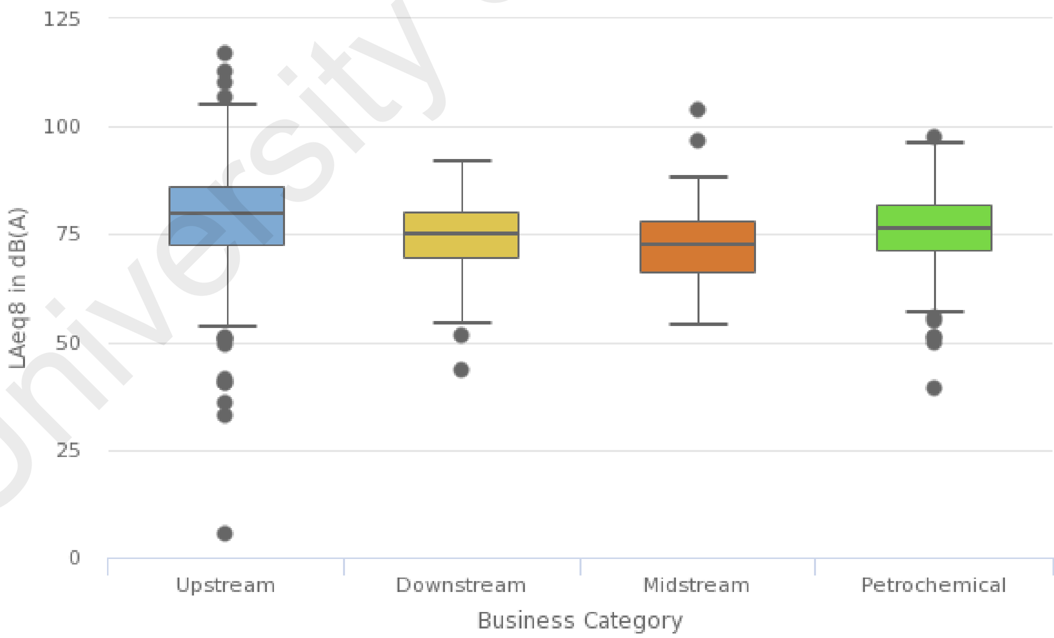

Figure 4.2: Boxplot to compare L_{Aeq8} of respective business categories

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4.2.2 Comparison of personal noise exposure level (L_{Aeq8}) by installation categories

For Upstream exploration and production (E&P) installation, observations of Production platform L_{Aeq8} had an average of 84.3 dB(A) (*SD = 8.7, SE_M = 0.5, Min = 60.0, Max = 117.1*). For E&P - Terminal, the observations of L_{Aeq8} had an average of 71.2 dB(A) (*SD* = 11.1, SE_M = 0.8, Min = 5.6, Max = 90.3). For LNG under Midstream business, the observations of L_{Aeq8} had an average of 72.0 dB(A) (*SD* = 8.9, SE_M = 0.7, Min = 54.0, Max = 104.0). For Downstream Refinery, the observations of L_{Aeq8} had an average of 75.0 dB(A) (*SD* = 8.5, SE_M = 0.7, Min = 43.3, Max = 92.0). For Downstream Energy plant, the observations of L_{Aeq8} had an average of 74.2 dB(A) (*SD* = 4.7, SE_M = 0.96, Min = 66.0, Max = 85.0). For Petrochemical complex, the observations of L_{Aeq8} had an average of 76.0 dB(A) (*SD* = 8.7, SE_M = 0.5, Min = 39.2, Max = 97.4). Summary of descriptive and compliance statistics for each installation category as tabulated in Table 4.5 and Table 4.6 respectively.

Table 4.5: Descriptive statistics of personal noise exposure level (LAeq8) by installation categories

Installation category	N	Min dB(A)	Max dB(A)	Mean dB(A)	SD	50^{th} %-ile	95^{th} %-ile	SE_M
E&P - Production platform	274	60.0	117.1	84.3	8.7	84.2	99.0	0.5
E&P - Terminal	194	5.6	90.3	71.2	11.2	73.2	85.8	0.8
LNG	174	54.0	104.0	72.0	8.9	73.0	84.4	0.7
Downstream Refinery	172	43.3	92.0	75.0	8.5	76.1	85.7	0.7
Downstream Energy plant	24	66.0	85.0	74.0	4.7	74.0	80.0	1.0
Petrochemical complex	256	39.2	97.4	76.0	8.7	77.0	88.2	0.5

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Table 4.6: Compliance statistics of personal noise exposure level (L_{Aeq8}) by installation categories

Installation category	N	Mean dB(A)	SD	95% LCL	95% UCL	95% UTL
E&P - Production platform	274	84.3	8.7	83.3	85.3	97.0
E&P - Terminal	194	71.2	11.2	67.0	73.0	84.0
LNG	174	72.0	8.9	71.0	73.3	85.0
Downstream Refinery	172	75.0	8.5	73.2	76.0	85.0
Downstream Energy plant	24	74.0	4.7	72.1	76.0	83.0
Petrochemical complex	256	76.0	8.7	75.0	77.0	87.0

4.2.3 Comparison of personal noise exposure level (L_{Aeq8}) by work cluster

From the observations made on 15 work clusters, the followings were five (5) work clusters with the highest average L_{Aeq8} across the businesses;

1) **Offs. Prod. Tech.**, the observations of L_{Aeq8} had an average of 86.0 dB(A) (*SD = 9.05, SEM = 0.85, Min = 59.70, Max = 117.10*).
2) **Offs. Aux. Field.**, the observations of L_{Aeq8} had an average of 85.0 dB(A) (*SD = 7.52, SEM = 1.31, Min = 69.10, Max = 101.60*).
3) **Offs. Maint. Tech.**, the observations of L_{Aeq8} had an average of 83.2 dB(A) (*SD = 8.11, SEM = 0.76, Min = 62.10, Max = 106.80*).
4) **Norm. Maint. Cons.**, the observations of L_{Aeq8} had an average of 78.68 dB(A) (*SD = 8.97, SEM = 2.11, Min = 60.90, Max = 92.30*).
5) **Norm. Aux. Field.,** the observations of L_{Aeq8} had an average of 75.20 dB(A) (*SD = 8.17, SEM = 2.04, Min = 63.90, Max = 88.10*).

Summary of descriptive and compliance statistics for each work cluster as tabulated in Table 4.7 and Table 4.8 respectively. The results from this were used to determine at-risk workers and will be elaborated further in discussion section. Figure 4.3 provides visual aid to facilitate comparison of L_{Aeq8} across the work cluster.

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Table 4.7: Descriptive statistics of personal noise exposure level (L_{Aeq8}) by work cluster

Work cluster	N	Min dB(A)	Max dB(A)	Mean dB(A)	SD	50th %-ile	95th %-ile	SE_M
Norm. Aux. Field	16	64.0	88.1	75.2	8.2	75.0	87.0	2.04
Norm. Maint. Cons.	14	72.2	92.3	83.0	5.7	82.2	90.0	2.11
Norm. Maint. Tech	131	33.0	92.0	72.0	9.0	73.4	84.0	0.78
Norm. Op. Support	45	39.2	84.0	67.0	11.4	70.0	81.0	1.70
Offs. Aux. Field	33	69.1	102.0	85.0	7.5	83.4	98.3	1.31
Offs. Maint. Cons.	2	69.2	74.0	71.4	3.0	71.4	73.3	2.15
Offs. Maint. Tech.	115	62.1	107.0	83.2	8.1	83.0	98.0	0.76
Offs. Op. Support	6	74.0	105.1	84.0	11.4	80.4	101	4.67
Offs. Others	4	70.0	76.4	73.0	3.0	73.0	76.1	1.50
Offs. Prod. Tech	114	60.0	117.1	86.0	9.0	86.0	99.4	0.85
Shift. Lab. Tech	6	54.0	71.0	64.1	7.0	65.4	71.0	2.84
Shift. Maint. Tech	88	41.4	90.3	73.0	9.0	74.0	87.0	0.95
Shift. Op. Support	19	51.0	86.0	70.0	9.6	70.1	80.2	2.19
Shift. Prod. Supv.	6	61.0	81.0	70.0	7.0	68.4	79.0	2.87
Shift. Prod. Tech	495	5.6	103.8	75.0	9.1	76.0	87.0	0.41

Boxplot in Figure 4.3 provides comparison of the distribution of L_{Aeq8} within each work cluster.

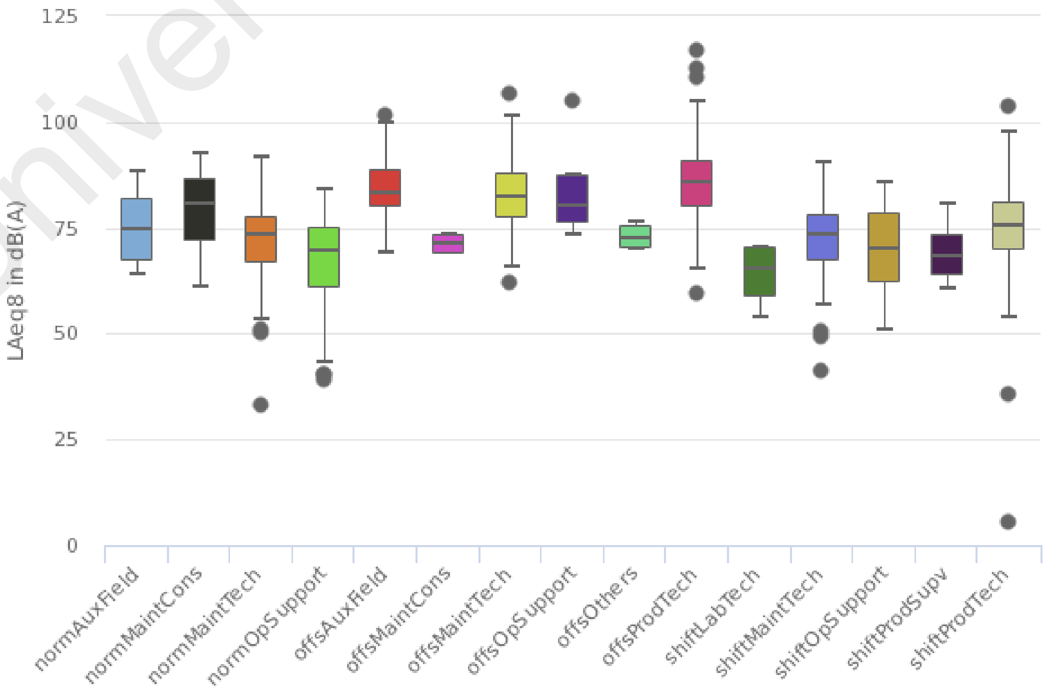

Figure 4.3: Boxplot to compare L_{Aeq8} of each work clusters

Table 4.8: Compliance statistics of personal noise exposure level (L_{Aeq8}) by work cluster

Work cluster	N	Mean dB(A)	SD	95% LCL	95% UCL	95% UTL
Norm. Aux. Field	**16**	**75.2**	**8.2**	**71.2**	**79.2**	**92.0**
Norm. Maint. Cons.	**14**	**83.0**	**5.7**	**80.0**	**86.0**	**95.0**
Norm. Maint. Tech	131	72.0	9.0	71.0	74.0	83.2
Norm. Op. Support	45	67.0	11.4	64.0	70.3	86.0
Offs. Aux. Field	**33**	**85.0**	**7.5**	**82.4**	**88.0**	**98.0**
Offs. Maint. Cons.	2	71.4	3.0	67.2	76.0	na
Offs. Maint. Tech.	**115**	**83.2**	**8.1**	**82.0**	**85.0**	**95.4**
Offs. Op. Support	6	84.0	11.4	75.0	93.1	118.2
Offs. Others	4	73.0	3.0	70.1	76.0	86.0
Offs. Prod. Tech	**114**	**86.0**	**9.0**	**84.3**	**88.0**	**100.0**
Shift. Lab. Tech	6	64.1	7.0	59.0	70.0	85.0
Shift. Maint. Tech	88	73.0	9.0	71.1	75.0	87.0
Shift. Op. Support	19	70.0	9.6	66.0	74.3	89.0
Shift. Prod. Supv.	6	70.0	7.0	64.4	76.0	90.3
Shift. Prod. Tech	495	75.0	9.1	74.2	76.0	87.4

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4.2.4 Discussion on compliance status based on 100% DND

From Figure 4.4, the 23% non-compliance cases, close to 70% were on meeting 85 dB, 3dB requirements. This exclude potential non-compliance from re-evaluation of compliance status to existing regulations (approx. 10%).

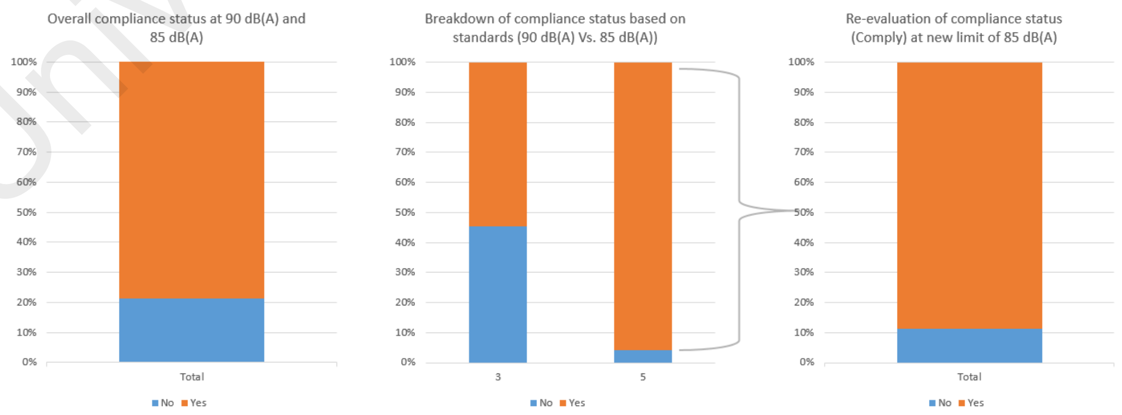

Figure 4.4: Evaluation of compliance to noise limit of 90 dB(A) and 85 dB(A) based on 100% DND

Upstream offshore facilities especially may face challenges in meeting the revised Noise Regulations. Focused - intervention to prevent exposure exceeding PEL for the following groups; 1) Multi-skill offshore production and maintenance technician; and 2) Offshore manpower support and maintenance contractors (e.g., crane operators, roustabout)

The study observed signs of over-reliance on HPD to protect workers from noise exposure exceeding permissible exposure limit as indicated in Figure 4.5. This study concluded that hazard of high noise level still present and effectiveness of HPD heavily subjected to worker's compliance and suitability of HPD. A comprehensive study on the effectiveness of HPD in reducing noise exposure conducted by NIOSH, US, found that the effectiveness drop to more than half of assigned NRR when workers only wear it partially during working hours. This is typical scenario where worker is required to remove their HPD for a brief period of time to communicate or to regain comfort after wearing HPD for a period of time.

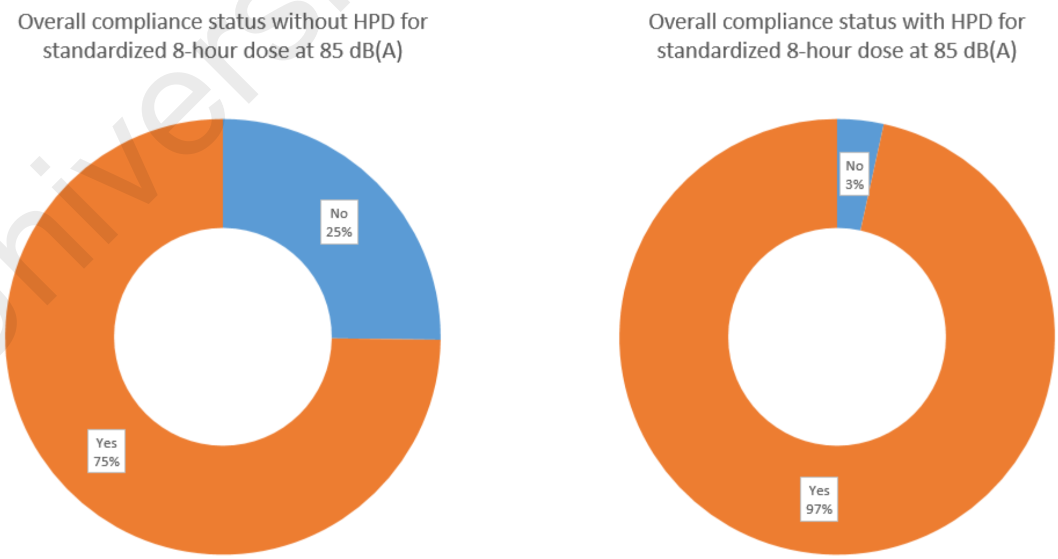

Figure 4.5: Overall compliance status evaluated based on 100% DND with & without HPD

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4.2.5 Conclusion and discussion of DND results based on AIHA Noise Exposure Control Category

Conclusion made based on DND showed that approximately 86% (952) of the samples were concluded as Rating 3 (50% - 100% DND) or below, 11% (150) at Rating 4 (> 100% DND) and 3% (31) at Rating 5 (> 500% DND). Upstream business contributed to the highest proportion of working clusters assigned as Rating 4 was 61% (72) or Rating 5 was 77% (24). The proportion recorded by upstream business was significantly higher as compared to the second highest, which was from petrochemical business with contribution to Rating 4 was 19% (23) and Rating 5 was 13% (4).

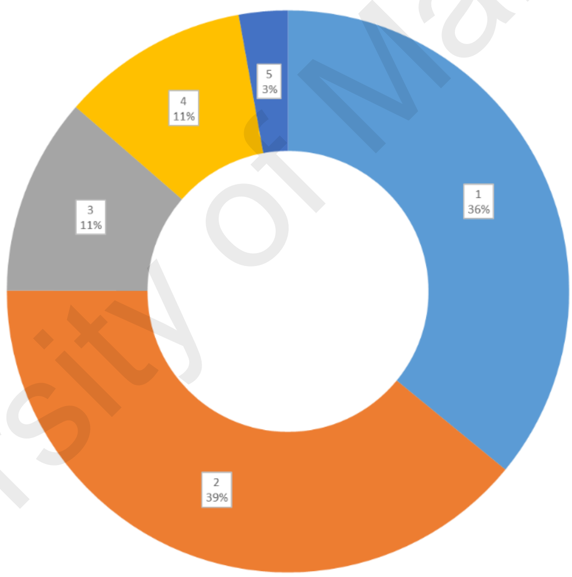

Figure 4.6: Pie chart showing the breakdown of ratings based on AIHA Noise Exposure Control Category in overall business category

Comparison made between business category found that, approximately 20% (96) of DND in upstream business were categorized in Rating 4 and Rating 5 category. Downstream and Petrochemical business recorded above 10% (23 – 27) of its sample population in Rating 4 and Rating 5. In contrast, midstream recorded lowest proportion of its sample population with only 2% (4) of total samples.

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Table 4.9: Number samples from personal noise exposure monitoring by facilities by business categories

Business category	N	AIHA Noise Exposure Control Category					Grand Total
		1	2	3	4	5	
Upstream	476	28%	36%	16%	15%	5%	100%
Downstream	196	44%	37%	7%	11%	1%	100%
Midstream	174	50%	43%	5%	1%	1%	100%
Petrochemical	256	35%	43%	11%	9%	2%	100%

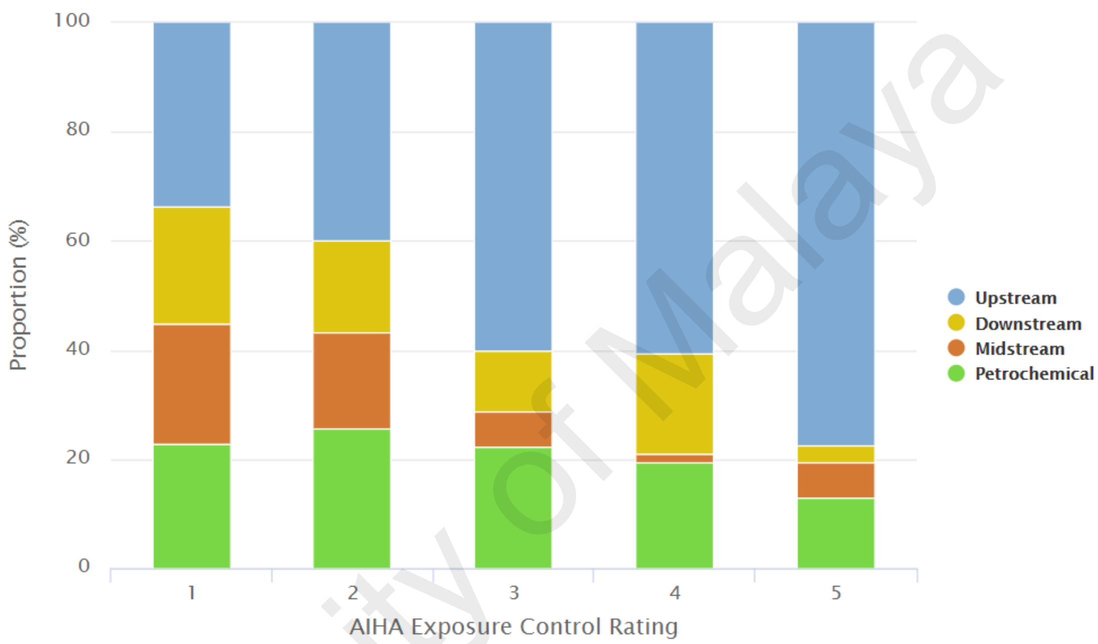

Figure 4.7: Bar chart showing the comparison between business category of ratings distribution based on AIHA Noise Exposure Control Category

Deeper investigation was done to identify work cluster at-risk to be exposed to noise level exceeding PEL. From the samples we classified work cluster as at-risk when more than 10% of DND were categorized as Rating 4 or Rating 5 in total. From the data presented in Table 4.9, the followings are work cluster at-risk in order from the highest to the lowest;

1) Offs. Prod. Tech (37%)
2) Offs. Aux. Field (36%)
3) Offs. Maint. Tech. (26%)
4) Norm. Maint. Cons. (23%)

5) Norm. Aux. Field (19%)

6) Offs. Op. Support (17%)

Table 4.10: Number samples from personal noise exposure monitoring by facilities by business categories

Work cluster	N	AIHA Noise Exposure Control Category					Grand Total
		1	2	3	4	5	
Norm. Aux. Field	16	50%	19%	13%	19%	0%	100%
Norm. Maint. Cons.	14	22%	39%	17%	17%	6%	100%
Norm. Maint. Tech	131	48%	44%	6%	2%	0%	100%
Norm. Op. Support	45	67%	29%	4%	0%	0%	100%
Offs. Aux. Field	33	6%	48%	9%	21%	15%	100%
Offs. Maint. Cons.	2	50%	50%	0%	0%	0%	100%
Offs. Maint. Tech.	115	12%	36%	26%	19%	7%	100%
Offs. Op. Support	6	17%	50%	17%	0%	17%	100%
Offs. Others	4	50%	50%	0%	0%	0%	100%
Offs. Prod. Tech	114	4%	35%	24%	28%	9%	100%
Shift. Lab. Tech	6	100%	0%	0%	0%	0%	100%
Shift. Maint. Tech	88	51%	35%	7%	7%	0%	100%
Shift. Op. Support	19	63%	32%	0%	5%	0%	100%
Shift. Prod. Supv.	6	83%	17%	0%	0%	0%	100%
Shift. Prod. Tech	495	39%	42%	9%	8%	1%	100%

4.3 Results and analysis of maximum exposure limit

The intend to analyze maximum exposure level is to characterize typical range by each business and later identify the possible scenario which exposed the workers to such exposure level. Table 4.10 summarizes L_{max} to be compared against 115 dB(A) as stipulated by FMA 1967. The mean L_{max} of sample population was 107.1 dB(A) with standard deviation of 9.3 dB(A). Computed statistical compliance concluded with 95% confidence level that the true mean of L_{max} values for the oil and gas population falls within the range of 106.3 dB(A) to 108.0 dB(A). Based on that we can conclude that all workers from the respective business category are exposed to below the regulatory limit. However, based on the samples, it is estimated that there is a 95% probability that 10% of the workers will be exposed to L_{max} at or higher than 119.1 dB(A).

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Table 4.11: Descriptive statistics of L_{max} by business categories

Business category	N	Min dB(A)	Max dB(A)	Mean dB(A)	SD	50th %-ile	95th %-ile	CV
Upstream	325	83.0	130.4	106.3	9.0	107.0	121.0	0.08
Downstream	124	96.0	145.4	113.0	7.6	113.0	127.3	0.07
Petrochemical	220	83.3	138.3	105.6	10.0	106.0	120.0	0.1

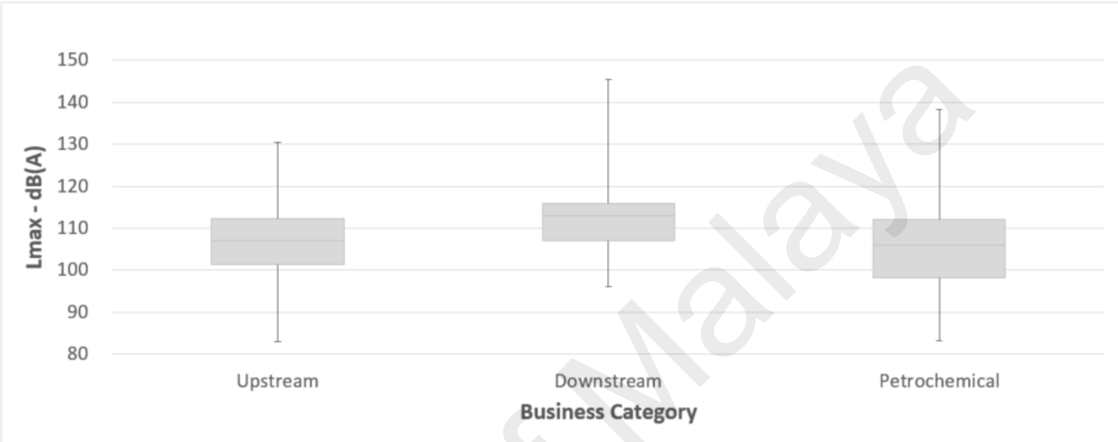

Figure 4.8: Boxplot to compare L_{max} of individual business category

Table 4.12: Compliance statistics of L_{max} by business categories

Business category	N	Mean dB(A)	SD	95% LCL	95% UCL	95% UTL
Upstream	325	106.3	9.0	105.3	107.3	118.6
Downstream	124	113.0	7.6	112.0	114.3	124.0
Petrochemical	220	105.6	10.0	104.3	107.0	119.1

4.3.1 Discussion and conclusion on compliance status to L_{max} regulatory limit of 115 dB(A)

Based on compliance statistic, based on the data, it was concluded that all business categories was in compliance to L_{max} of 115 dB(A), with Downstream business approaching the limit. In addition to that, it is estimated with 95% probability, that 10% of the population is exposed to noise level exceeding the PEL for L_{max}.

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4.4 Result and analysis of peak exposure level

The intend to analyze L_{peak} is to characterize typical range by each businesses and later identify the possible scenario which exposed the workers to such exposure level. Table 4.12 summarizes L_{peak} to be compared against 140 dB as stipulated by FMA 1967. The Overall L_{peak} sample mean was 136.3 dB with standard deviation of 7.5 dB. Statistical compliance concluded with 95% confidence level that the true mean of L_{peak} values for the oil and gas population falls within the range of 137.0 dB to 138.0 dB. Based on that, we can infer that all workers from the respective business category are exposed to below the regulatory limit. However, based on the samples, it is estimated that there is a 95% probability that 10% of the workers will be exposed to L_{peak} at or above 147.0 dB, hence increasing the risk of hearing impairment among the workers.

Table 4.13: Descriptive statistics of peak noise exposure level (L_{peak}) by business categories

Business category	N	Min dB(A)	Max dB(A)	Mean dB(A)	SD	50^{th} %-ile	95^{th} %-ile	CV
Upstream	325	106.4	163.1	135.2	7.1	130.2	144.0	0.05
Downstream	124	113.0	149.0	141.0	7.2	145.0	147.3	0.05
Petrochemical	220	119.0	147.0	136.0	7.3	135.0	145.3	0.05

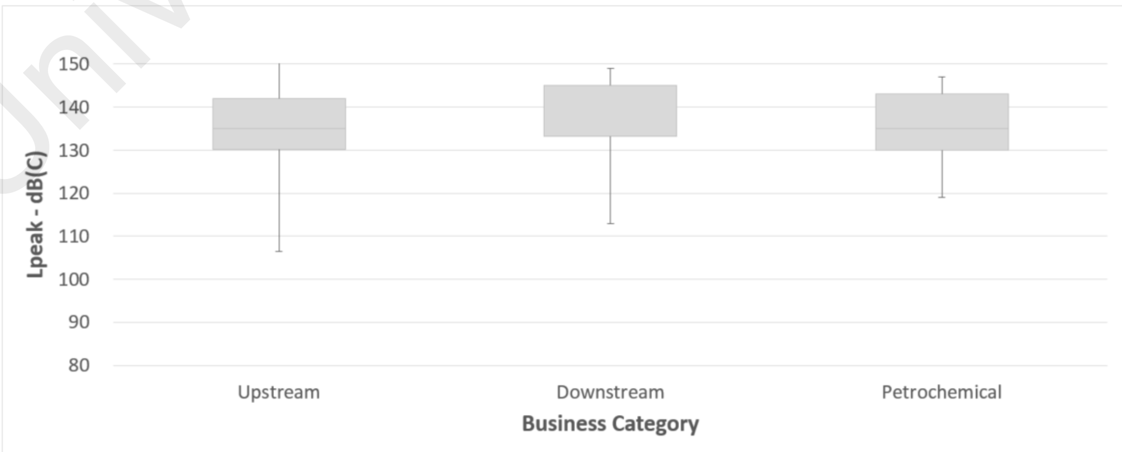

Figure 4.9: Boxplot to compare L_{peak} of individual business category

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Table 4.14: Compliance statistics of peak noise exposure level (L_{peak}) by business categories

Business category	N	Mean dB(A)	SD	95% LCL	95% UCL	95% UTL
Upstream	325	135.2	7.1	134.4	136.0	144.0
Downstream	124	141.0	7.2	140.0	142.0	147.0
Petrochemical	220	136.0	7.3	135.0	137.0	145.0

4.4.1 Discussion and conclusion on compliance status to L_{peak} regulatory ceiling limit of 140 dB

Based on compliance statistic, it was concluded that, except for Downstream, all business categories are in compliance to L_{peak} PEL of 140 dB. In addition to that, it is estimated with 95% probability, that 10% of the population in all business categories are at risk to be exposed to noise level exceeding the PEL for L_{peak}.

4.5 Result and analysis of area noise exposure

Area noise exposure in noise exposure monitoring report is intended to catalogue dominant noise sources present within the facilities. The outcome of the commonly presented as noise contour or zoning area. Table 4.13 provides summary statistics of type of dominant noise sources in this study.

Table 4.15: Summary statistics of average sound pressure level (L_{avg}) of different type of noise sources

Type of noise sources	N	Min dB(A)	Max dB(A)	Mean dB(A)	SD	50^{th} %-ile	95^{th} %-ile	CV	95% UTL
Equipment	535	65.0	108.2	89.0	5.7	89.0	99.3	0.06	96.8
Process	145	56.0	116.0	90.4	7.2	90.3	101.5	0.08	101
Activities	4	86.1	91.4	89.4	2.3	90.0	91.3	0.03	99.1
Area	327	63.3	97.0	81.0	5.7	81.0	89.0	0.07	88.9

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4.5.1 Summary of equipment as noise sources

Equipment were generally divided into either mechanical or rotating category based on ISO equipment classification as described in Section 3 – Methodology.

Table 4.16: Summary statistics of average sound pressure level (L_{Avg}) of noise sources under equipment category

Type of noise sources	N	Min dB(A)	Max dB(A)	Mean dB(A)	SD	50^{th} %-ile	95^{th} %-ile	CV	95% UTL
Rotating	**460**	**73.0**	**108.2**	**89.0**	**5.2**	**89.0**	**99.1**	**0.06**	**100.9**
Blowers & Fan	66	77.0	108.2	88.3	6.8	87.2	102.0	0.08	102.0
Combustion engine	5	85.1	93.0	90.0	3.1	91.2	92.4	0.03	100.4
Compressor	124	82.1	105.0	92.2	4.7	92.0	101.0	0.05	99.3
Electric generator	2	89.0	98.4	94.0	6.7	94.0	98.0	0.07	na
Electric motor	27	78.0	95.1	89.3	3.6	89.0	94.1	0.04	96.0
Pump	226	73.0	103.0	87.4	4.4	87.2	95.0	0.05	93.1
Turbine	11	84.4	95.0	89.0	3.2	89.2	94.4	0.04	97.0
Mechanical	**232**	**65.0**	**116.0**	**90.0**	**6.7**	**89.3**	**101.0**	**0.07**	**102.0**
Ejector*	2	92.0	99.0	95.3	4.7	95.3	98.3	0.05	na
Filter / strainer*	1	86.0	86.0	86.0	na	na	na	na	na
Flare*	1	72.0	72.0	72.0	na	na	na	na	na
Furnace*	1	89.4	89.4	89.4	na	na	na	na	na
Heat exchanger*	15	85.0	99.3	89.0	4.7	87.0	99.0	0.05	99.3
Heater / Boiler*	12	70.3	100.0	89.0	7.2	89.0	98.3	0.08	104.5
Piping*	29	85.0	106.0	90.3	4.3	89.0	96.4	0.05	97.0
Pressured vessel*	47	65.0	99.0	84.0	7.2	85.0	95.0	0.09	96.0
Valve*	35	81.3	103.3	91.1	5.4	90.1	102.0	0.06	100.3
Vent*	66	84.5	116.0	94.0	5.7	92.4	102.1	0.06	103.0

[a] process static equipment

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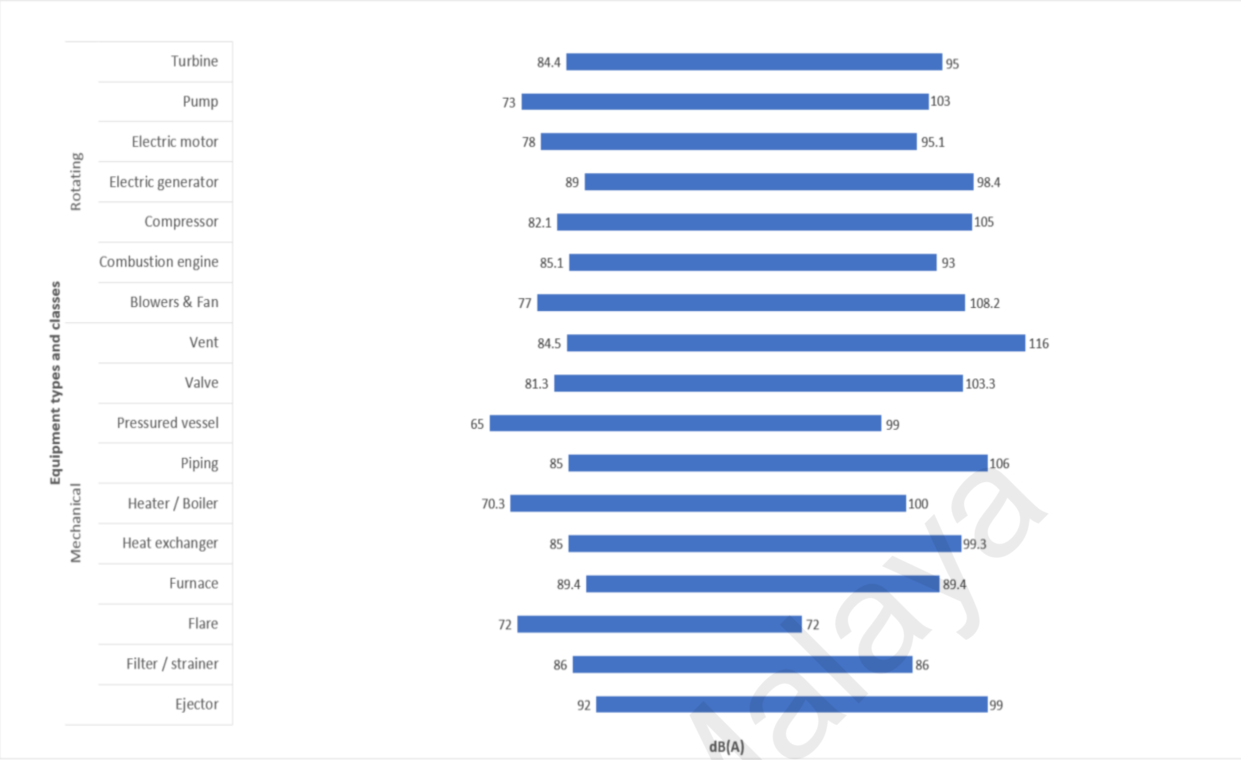

Figure 4.10: Bar chart of equipment noise sources sound pressure level (L_{Avg})

4.5.2 Summary of process as noise sources

Besides noise generated by process equipment as listed in Table 4.13, other process noise sources that were not generated by that equipment such as steam traps, steam leaks or air leaks (whistling).

4.5.3 Summary of activities as noise sources

Limited number of samples to generalize the findings. Examples of noise sources recorded from activities where human are continuously required to be present are Extrusion, Cell Palletizing, Bagging and Stamping activities. All the samples were from Petrochemical business.

Table 4.17: Summary statistics of average sound pressure level (L_{avg}) of categorized under Activities

Type of noise sources	N	Min dB(A)	Max dB(A)	Mean dB(A)	SD	50th %-ile	95th %-ile	CV	95% UTL
Activities	4	86.1	91.4	89.4	2.3	90.0	91.3	0.03	99.1

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4.6 Discussion on the challenges and limitation of the study

This study was intended to identify and characterize noise sources and worker's exposure within oil and gas industries in Malaysia. The insight provided by this study, will enhance our understanding of the potential compliance issues and challenges within the respective industries or SEG. With the information, this study will enable the authorities and industry in optimizing their resources with more specific solutions or focused intervention plan to address the issues, hence gearing the industry better towards the upcoming revised noise regulations. However, this study met the objectives not without any challenges. This section intended to share the challenges and limitation experienced when completing this study.

4.6.1 Incomprehensive noise assessment and exposure monitoring by NCP

FMA (Noise exposure) regulations, 1989 specified that compliance status is determined after the deduction of effective NRR from the measured L_{Aeq8}. However, the study observed that, in all assessment reports, no remarks ever been made to discuss on the compliance status of HPD. NCP commonly make a remark on the availability of HCP program or HPD issuance procedure of the respective facilities. General assumption was made, that workers that received HPD from the employer will wear it when entering noisy area. Hence, since the compliance status is all green, and the exposure level after HPD is way below the PEL, no recommendations or specific interventions will be proposed by the NCP.

Relying only on exposure data to make conclusion on the exposure status of SEG is insufficient and may lead to inaccuracy in judgement. NCP should also include input from the workers and familiarize with their routine. This can be done in so many ways such as interview or reviewing their daily activity log, which is one of the requirements during the monitoring. However, the study noticed, in most cases, the handwriting on the

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activities log were illegible and difficult to read. Valuable information such as specific tasks being performed, tools used, dominant noise sources observed at site or engineering control in place were not sighted on the most activities log.

NCP usually not a trained chemical health risk assessor. Hence, the present of ototoxic within the SEG may be left unnoticed. As the evidences are strong on the effect of ototoxic chemicals towards hearing impairment and hearing loss, it should be area where NCP should include during their assessment.

4.6.2 Incomplete noise exposure assessment reports

Data for this study were extracted from noise exposure assessment reports conducted at the respective facilities. The most common challenges faced during the collection of the reports were incomplete reports. Incomplete report was described when report in soft copy is still in draft mode, critical information which normally appended in the report were missing such as instrument data logging record, calibration certificate, and calculation spreadsheet. The completeness of the report is crucial to ensure the validity and quality of the report hence the quality of data to be analyzed.

4.6.3 Inaccuracy of reporting

During the process of review and extraction of exposure monitoring from the report, the observed incorrect instrument setting used for the monitoring purpose. In addition to that, verification done on the final result for DND also found a number of cases of miscalculations. This is more common when the shift is not regular (e.g., 10-hour, 12-hour). Fortunately, it is possible to perform a reverse calculation and salvage the result from the personal exposure monitoring for the purpose of this study.

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4.6.4 Insufficient number of samples from specific SEG

Total number of personal exposure samples acquired for this study is large enough to provide reliable estimation for overall true oil and gas population mean and for most job functions which hold by the company permanent staff. However, the study encountered a few cases where the dataset was too small to compute reliable and meaningful statistics or estimates. The study had very limited data from the contractors engaged by the company, as well as workers from other oil and gas operating company in Malaysia. As a result, generalization of the findings or any conclusions derived from this study must be done with care.

4.6.5 Insufficient information and samples on noise sources

The study also had limited dataset on all types of noise sources critically on the process as well as activities. From the understanding of the noise assessment and monitoring process, the study believes that, the main reasons for this was because, no specific guideline on area monitoring approach issued by the authority, we found the approach and completeness of the data collected on noise sources during noise area monitoring to be inconsistent from one NCP to another. These create challenge in analyzing data for noise source, hence, hindering its overall usefulness.

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CHAPTER 5: CONCLUSION & RECOMMENDATIONS

5.1 Conclusion

Noise legislation in Malaysia was promulgated only in the 90s with the released of Factory and Machineries Act (Noise exposure) regulations, 1989. The regulations, in summary, prescribed the need to perform noise monitoring, to establish HCP which includes employer's responsibility to provide resources for training, hearing protection device and audiometric testing programme. The regulations were later supplemented with more structured occupational disease reporting and notification regulation or known as NADOPOD under OSHA 1994. Almost 30 years since the regulations were introduced, NIHL remains as one of the most occupational diseases reported in Malaysia since the last decade. DOSH, a department under Ministry of Human Resources, is the agency that responsible to protect the safety and health of workers from hazards arises at the workplace. In the recent SoHelp conference, DOSH informed the attendees about the upcoming revision of Noise Regulation. The revised noise regulation emphasizes more on noise control at the source rather than relying on HPD to protect workers' hearing. The regulation will also introduce a requirement on periodic noise monitoring akin to CHRA under USECHH, 2000 Regulations. The penalty imposes by the revised regulation will also increase significantly when compared to existing regulations.

The study conducted with the objective to study the gaps in practices using compliance status as a measure. At the same time, the study was attempted to characterize noise sources that are common in oil and gas industries and exposure level of workers based on their job function and their business sector. The data for this study were collected from noise exposure monitoring report of the facilities selected to represent the business sectors. Result and analysis performed from this study will provide better insight to industries, specifically in oil and gas, on the potential challenges in complying to the upcoming noise regulations.

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Statistical analysis was performed on parameters used to evaluate workers' exposure and compliance namely L_{Aeq8}, L_{max} and L_{peak}. The analysis was performed at several level in order to characterize and understand the noise exposure level with respect to their business, type of facilities and their job functions. In general, the sample average L_{Aeq8} for oil and gas industries is 76.3 dB(A) (95% CI = 76.3 – 78.0). Therefore, based on compliance statistics, since the UCL is below the PEL of 90 dB(A) for 8-hour exposure, it is concluded that overall oil and gas industries is in compliance with the existing noise limit as well as expected revised noise limit of 85 dB(A). However, a conservative prediction based on UTL estimated with 95% probability that 10% of the workers' exposure may still exceed 90 dB(A). Further exploration of the data suggested that upstream business, specifically on their exploration and production facilities may face challenges in complying to the lower noise exposure limit. Group of workers from upstream business whom at risk to exceed 85 dB(A) are from contractors, manpower support, crane operators, operation and maintenance technician. The high exposure level among workers on exploration and production platform may be due to the fact the working on space constraint facilities and spend more hours around the processing area as compared to workers at onshore terminal or facilities. Maximum noise limit of the sample population was 107.1 dB(A) (95% CI = 106.3 – 108.0). Based on that, the study concludes, oil and gas industries in general do not have issues in compliance to that limit. However, there is 95% probability that 10% of the workers will be exposed to L_{max} at or higher than 119.1 dB(A). Average sample mean exposure level to L_{peak} was 136.3 dB (95% CI = 136.0 – 137.0). Inference made from compliance statistic, found that, except for Downstream, all other business categories are in compliance to L_{peak} PEL of 140 dB. In addition to that, it is estimated with 95% probability, that 10% of the population in all business categories are at risk to be exposed to noise level exceeding the PEL for L_{peak}.

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The study also attempted to characterized common noise sources in oil and gas industries. However, the insight gained in the characterization process were limited due to insufficient samples either from the business or for the specific equipment. As such, it worth to note on the limitation of generalizing findings or conclusions made based on data from area noise monitoring of this study. Details results and discussion pertaining to noise source available at Chapter 4 of this report. Key learnings and challenges during the process were captured and intervention plans were proposed for future studies.

In attempt to facilitate decision making process based on noise exposure monitoring data, this study adopted AIHA Noise Exposure Control Category protocol to conclude exposure data based on DND. Using this approach, each work cluster will be assigned with an exposure control rating (i.e., 1 – 5) based on the DND values. Generic recommendations and controls will be proposed based on the rating assigned. From this study, approximately 86% of the samples were concluded as Rating 3 (50% - 100% DND) or below, 11% at Rating 4 (> 100% DND) and 3% at Rating 5 (> 500% DND). Upstream business contributed to the highest proportion of working cluster assigned as Rating 4 (15%) or Rating 5 (5%). Work clusters were classified as at-risk when more than 10% of its sample population were in Rating 4 and Rating 5 category.

Learnings from this study hopefully will provide facilitate the authorities, and industry in the implementation of revised noise regulation. This study recommend that company consider more robust approach such as adopting Buy-Quiet policy or Quiet-by-Design to eliminate or minimize noise at the source. This will prevent over-reliance on HPD to protect our workers' precious hearing.

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5.2 Recommendations for improvement at the workplace

5.2.1 Establishment of noise exposure assessment strategy

Throughout the process of extracting the data from noise exposure monitoring report, the study found several important gaps in the monitoring activities which may result in less accurate noise assessment and conclusions made from the exposure data collected. Besides incorrect instrument setting (e.g., criterion, TL) or monitoring duration covered less than 80% of working hours, we observed that number of samples collected to represent specific SEG were insufficient (e.g., samples from contractors). Sufficient number of samples is critical to ensure the conclusion made on the data, reach certain statistically confidence level (i.e., 95% CL), hence increase the reliability of the conclusion made for the SEG.

Verification and discussion with focal person of the respective facilities revealed that, the issues may be resulted from the unavailability of noise assessment strategy to guide NCP when performing noise assessment and monitoring campaign. NCP usually engaged by the company for specific period of time, usually 5 working-day, to perform the assessment, noise exposure monitoring and produce report within 1-month after the campaign. Without the sampling strategy, NCP have a very limited experience on the SEG, hence making inaccurate judgement on who, what and where to measure.

Based on that learning and experience, this study recommendation is to develop noise exposure assessment strategy specific for identified SEG. Sampling strategy will complement noise assessment activities by prescribing the quantity of samples for specific similar exposure group (SEG), activities or tasks to be monitored as well as measurement approach, based on input from previous assessment. This will reduce the possibilities of insufficient number of samples or oversight on non-routine tasks that need

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to be assessed. AIHA recommended measurement strategies based on type of work as in Figure 5.1.

Type of Work	*Measurement Strategy*		
	Task level	**Job level**	**Full day**
Fixed workstation – simple or single task	OK; P		
Fixed workstation – complex or multiple tasks	OK; P	OK	OK
Mobile worker – predictable work, small # tasks	OK; P	OK	OK
Mobile worker – predictable work, large # tasks or complex work pattern	OK	OK	OK; P
Mobile worker – unpredictable work pattern		OK	OK; P
Fixed or mobile worker – multiple tasks with unspecified duration		OK; P	OK
Fixed or mobile worker – job goal based w/no specific tasks		OK; P	OK

Figure 5.1: AIHA noise measurement strategies based on type of work based

5.2.2 Strengthening noise exposure assessment and monitoring practices by noise competent person (NCP)

Factory Machinery (Noise Exposure) Regulations 1989 stipulated that noise assessment or noise exposure monitoring must be performed by competent person registered with DOSH. Registered NCP is a scarcity in Malaysia. Rarely a company hired in-house NCP or develop HSE practitioner to become NCP as it is not part of business requirement or license-to-operate. Common practice in the industry is to engage external NCP to conduct noise assessment at their facilities as part of HCP elements. It is critical to note that the noise competent person may be proficient in the measurement of noise, however, contract owner must be able to provide direction and guidance to the NCP pertaining to the noise sources (i.e., equipment, process, activities). This will ensure data and findings collected from the noise assessment and measurement be able to evaluate the noise risks within the SEG accurately, hence optimizing resources required for HCP implementation. As such, engagement with NCP on the company noise assessment strategy as well as sampling sharing of lesson learned and best practices will help strengthening and add value to the noise assessment performed by the NCP.

5.2.3 Adoption of Quiet-by-Design and Buy-quiet policy as proactive intervention

According to noise hierarchy of control described in Chapter 2, selection of noise control can be based on either making the workplace safer (i.e., quieter) or making the worker safer (i.e., HCP, HPD). Studies also reported on the challenges in the implementation of HCP, especially in developing countries. Hence, the former is relatively preferred. QBD or BQ aimed to make the work place quieter by designing it right for the new facilities, or by preventing introduction of new noise sources into the facilities. BQ requires all new equipment or production procedures (e.g., operating parameter) to adhere to a predefined noise exposure limit, less than 85 dB(A) L_{Aeq8}. This can be part of existing HCP in the company. Enhancement of HCP policy or procedure may include management approval prior to equipment purchase. Any new facilities or expansion project should be designed with noise exposure limits in mind.

5.2.4 Adoption of best available technology to minimize noise level at the existing facilities

Reducing the employee noise exposures may be accomplished by examining the source of the noise and implementing engineering solutions to reduce the noise at the source. Other options which should be considered are to reduce the noise between the source and the employee or provide a noise reduction enclosure around the employee.

5.2.5 Additional intervention strategy for workers at-risk of PTS or NIHL

Audiometric testing is required under noise regulations when workers exposed to noise level at or exceeding action limit (50% DND). Results from audiometric testing will identify individual workers with hearing impairment (i.e., TTS, STS, PTS) as well as

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hearing loss. Further analysis of the audiometric results can reveal specific workers who have the potential to develop hearing threshold shift. This can be achieved by analyzing threshold shift rates of the respective business, departments or job positions. STS can be used as an early indicator or trigger point for intervention, subsequently preventing or minimizing of risk of PTS.

Once identified, workers with the STS above average rates can be included for additional intervention. Another approach that worth considering is to include workers with extreme noise exposures (i.e., $L_{Aeq8} \geq 105$ dB(A) and require double HPD) can be included in this intervention approach as well.

5.2.6 Enhancement of audiometric testing frequency for workers at-risk

The audiometric testing interval can be reduced with intent to evaluate hearing performance of high risk workers more frequently. For example, workers with $L_{Aeq8} \geq$ 105 dB(A) may be required to go for audiometric testing in every 6 months regardless of previous audiometric result.

Another consideration to be given for the additional audiometric testing is for SEG with combined noise and ototoxic chemical exposures. The rationale for this recommendation is exposure to ototoxic chemicals in combination or noise exposure, even at level below PEL (e.g., ≤ 85 dB(A)) may increase the chances of getting NIHL. The key to this strategy is early detection, as it will increase the probability of preventing temporary threshold shift to develop into PTS or hearing loss.

5.2.7 Awareness training for the management

Awareness training for managers and others job functions essential for enforcement of HCP activities is critical in ensuring successful implementation of HCP. The training will equip the managers and key decision makers in the company (e.g., project manager,

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maintenance and operation engineer, procurement) the knowledge of noise and hearing loss prevention. Ability to rationalize the HCP requirements will improve the motivation for administering an effective HCP.

5.2.8 Improvement of compliance on HPD usage among at-risk workers on- and off-the-job

As recommended earlier, workers whom likely to develop threshold shift because of an early NIHL indicator, or high risk workers (i.e., $L_{Aeq8} \geq 105$ dB(A), ototoxic chemical exposure) can be provided with additional training and individual coaching. The employee can be coached on hearing loss prevention, and the suitability of HPD (i.e., NRR, comfort) issued to worker at-risk should be verified and documented. These workers should be encouraged and provide with safe platform for them to communicate on their concern with regard to the noise exposure and controls that in place. Periodic personal protective equipment checks can be conducted randomly throughout the year, with an emphasis on proper hearing protection fit and use. HPDs should also be checked for wear, damage, and need for replacement.

Because of the synergistic effect of many chemicals with noise, many companies with combined exposures to noise and ototoxic chemicals require wearing a respirator and hearing protection together as a first preventive mechanism against hearing loss whenever chemicals and noise are present together.

As it is impossible to isolate noise in and off-the-job, workers should be encouraged to use HPD when exposed to hazardous noise during recreational activities. By including non-occupational noise exposure information in the employee training and providing HPD for off-the-job use, the employee may be more receptive and able to practice hearing loss prevention for all hazardous exposures, both at work and outside the workplace.

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5.2.9 Accurate assessment reports and systematic record keeping

The study acquired data from noise exposure monitoring reports. While in the process of extracting the data and reviewing the reports, the study observed and recorded issues with the reports for future improvement. Common issues with the reports observed during this study were inadequate information, inaccurate interpretation or conclusion of exposure monitoring data and generic recommendations to control noise exposure.

The following information are minimum that need to be reported accurate by NCP in the report they prepared following noise assessment or monitoring;

1) Area noise exposure monitoring should include the following information
   i. Equipment tag
   ii. Equipment category based on ISO 14224
   iii. Process / activities involves
   iv. Number of workers that likely exposed / SEG
   v. Full monitoring datasheet

2) Personal exposure monitoring
   i. Activity log
   ii. Monitoring log
   iii. Dominant noise source during monitoring
   iv. Estimated exposure time (monitoring vs. routine vs. non-routine)

In addition to that, the study shall also evaluate the adequacy of engineering control implemented at the noise sources.

Systematic collection of noise assessment and exposure monitoring data is essential in developing more accurate exposure profiles, for the business, job functions or activities. Accurate reports and documentation of exposure assessment or monitoring will enable

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better decision making and more robust risk management recommendation by the policy makers or HSE practitioners in the industries. The followings are minimum records to be retained to ensure effective HCP implementation within an organization:

1) Noise assessment report
2) List of workers or SEG included in the HCP
3) Noise sources register and noise mapping
4) Audiometric testing and medical history records, including notifications to workers,
5) HPD selection criteria, specification (i.e., brand, model, NRR) and issuance record
6) Noise awareness training records
7) Noise control studies, including projects undertaken to reduce exposure,
8) Procedure or company policy pertaining HCP
9) Compliance audit checklist
10) Calibration certification for noise measurement instruments (e.g., SLM)

5.3 Recommendation for future studies

5.3.1 Study design and scope

This study met the objectives it sets prior. However, a lot more can be done in order to strengthen our understanding on noise issues within oil and gas industries in Malaysia. Better understanding of the issues will help us to identify and proposed more specific solutions or intervention plan to address the issues.

Total number of personal exposure samples acquired for this study is large enough to provide reliable estimation for overall true oil and gas population mean and for most job functions hold by the company permanent staff. However, the study acknowledged the lacking of data from contractors as well as other oil and gas operating company in

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Malaysia. Samples from contractors were too small to compute reliable and meaningful statistics or provide estimation for the respective work cluster. Recommendation from this learning for future studies is to acquired representative number of samples from contractors as well as other oil and gas companies. This is crucial so as to ensure results and findings from the studies will have a broader application across the industries.

The study also experienced similar issues with the number of samples for noise sources. Since there is no specific guideline on area monitoring approach issued by the authority, we found the approach and completeness of the data collected on noise sources during noise area monitoring to be inconsistent from one NCP to another. These create challenge in analyzing data for noise source, hence, hindering its overall usefulness. Future studies may consider to adopt recommendations from this study on minimum information to be collected for noise sources.

Moving forward, since a lot of studies have reported the relationship between ototoxic and increase risk of NIHL. Future studies can include data from chemical exposure monitoring to deepen the understanding when workers expose concurrently to ototoxic chemicals and noise. Future studies can also explore the prevalence of hearing impairment or hearing loss within SEG where the ototoxic chemicals are present.

Finally, more robust statistical analysis can be performed to identify patterns and draw actionable insights or to estimate the likelihood of exposure level exceeding PEL in the respective business, facilities, activities or job functions.

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