Risk and Reliability Analysis of the Effect of Underwater Noise Pollution towards MarineAnimals

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Abstract—Underwater sound is important for the underwater creatures. It is useful for the navigation, food finding, mating, and also predator detection. The natural phenomenons in the marine environment that produce noise include waves, wind, surf, lightning, precipitation, animals' sound and also the earthquakes. The frequency of the natural sound was usually below 100 Hz, but rain and waves sounds dominate higher frequencies. However, some human activities can cause the underwater noise pollution such as the sound produced by the ships, sonar, pile driving, dredging, oil and gas explorations and also military activities. The effect of man-made noise is a main threat to marine animals. Fish, in particular, was less attractive with the noisy environments and avoid areas where man-made noise levels are high.The presence of noise also could keep fish changes their way, behavior and reproduction. Our analysis has determined the cause, occurrence and the effect of the underwater noise pollution in the ocean towards marine animals. The overview from the results shows that shipping operation got the higher risk based on the evaluation of risk matrix rating which the identified risks are come from the high speed of the ships and sound emitted from the engine vibration in the hull of ships. Preliminary calculation involving the energy budget per year for anthropogenic noise shows that Underwater Noise Explosion emits higher energy per year which is 2.1 x 1015 J.

Index Terms—underwater sound, oxidative stress, FTA, FMEA, SERM, HAZID, HAZOP.

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1 INTRODUCTION

Sound is so important in the ocean because vision is limited in the great darkness of the deep sea where sound travels fast, far, and efficiently. As we all know, almost every living creature depends on sound as a primary sense for mating, hunting and survival. Besides, several species use sound to communicate for reproduction, feeding and navigation. As an example, bowhead whales; walrus; ringed, ribbon, and bearded seals; and other marine mammals depend on the sounds they make and hear to navigate, contact one another, court potential mates, find food, and avoid predators [1]. Furthermore, most marine animals, particularly fish, are dependent on sound, sometimes for all aspects of their life including reproduction, feeding, predator avoidance, and navigation. Unfortunately, very high received levels of sound can injure some internal systems [2], produce stress, such as oxidative stress [3,4] or even kill marine life. Scientists have reviewed the impact of sound on fish species around the world, especially noises made by oil and gas rigs, ships, boats, and sonar. Most

fishes hear well and sound plays an active part in their lives. "People always just assumed that the fish world was a silent one," says biologist Dr Hans Slabbekoorn of Leiden University, The Netherlands [5].

There is a growing concern about the impact of underwater noise pollution on marine animals. According to Ocean Mammal Institute, underwater noise pollution is defined as human-generated noise in marine environment. It is caused by use of explosives, oceanographic experiments, geographical research, underwater construction, ship traffic, intense active sonar and air guns used for seismic surveys for oil and related activities [6]. The aim of our study is to present fault tree analysis (FTA), Failure Mode Effect Analysis (FMEA) as qualitative analysis and the frequency and consequence analysis of the noise pollution towards marine animals with the direction of ecological and endocrine research in progress in this matter.

2. SOUND AND SOUND'S ROLE IN MARINE ANIMALS

There are sound sources in the ocean that produce noise levels much higher than 120 dB such as air guns used for oil exploration and geophysical research (216 - 230 dB), underwater construction, explosives, military sonar, large ships and acoustic harassment devices. From that research, the scientists have discovered that whales can reduce the sensitivity of their hearing to prevent damage from loud man-made noises, such as weapons testing, ship engines, and air guns used in oil exploration [7-9].

The sound's intensity is measured in decibels (dB). The noise present in the sea is comes from many different sources. Ambient noise is the sound that comes from water environment with different locations and frequencies. Natural physical

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phenomenon that contribute to underwater ambient noise includewater motion, as well as the effects of surf, rain, lightning, marine mammals and tides. The underwater noise also comes from man-made sources such as air guns used in oil and gas explorations, dredging, military activities, shipping and also sound sources used in oceanographic research. Anthropogenic noise can be broadly split into two main types: impulsive and non-impulsive sounds. Impulsive underwater noise is a loud, intermittent or frequent noise, such as those generated by piling, and seismic surveys. Continuous noise is defined as lower-level constant noises, such as those generated by shipping and wind turbines [10,11].

One of the special characteristic of marine animals is they are able to hear events all around them, no matter where their attention is focused. They have unique adaptations that enable them to communicate with each other, protect themselves, find food locations, and for navigation purpose. Sound is also important to fishes [12]. Some species of fish i.e. produce several of sound such as grunts, croaks, clicks and snaps. The role of sound to fish is to attract mates as well as to avoid the predators. Fish produce sounds in three ways, where the first one is from movement in water. Second, through muscles near their swim bladder that produce a relatively low frequency sound, on the order of hundreds of Hertz. The third one is by rubbing together skeletal parts of their body at relatively high frequencies in order of thousands of Hertz [13,14].

Fish have two sensory systems for detection of water motions: the inner ear (there is no outer or middle ear) and the lateral line system. The ear serves to detect sound up to hundreds or even thousands of Hz (depending on the species), whereas the lateral line detects low-frequency sound (e.g. <100 Hz), but is generally considered to be primarily a detector of water motion relative to the body [15]. Besides, sound can be thought of in terms of both particle motion and pressure fluctuations. Sensory hair cells in the inner ear and lateral line (both of which are very similar to those found in the mammalian ear) are stimulated by mechanisms that respond to particle motion and are responsible for converting these motions to electrical signals that stimulate the nervous system [16].

The lateral line system is found along both sides of the body and typically spreads out over the head region. It plays a dominant role in the detection of water motion and low-frequency sound at short distances (one or two body lengths). In contrast, the inner ear also detects sounds of much higher frequencies and from greater distances (probably via acoustic pressure since particle motion declines with distance more rapidly).

There may also be a direct mechanical connection between the swim bladder and the inner ear through a series of bones (the Weberian apparatus) such as in a large group of fish species (Otophysi) that includes goldfish (Carassius auratus) and catfish. Generally, the best frequency of sound that fish can hear is within 30–1000 Hz, while species with special adaptations can detect sounds up to 3000–5000 Hz. But, some exceptional species are sensitive to infrasound or ultrasound [17].

3. MATERIAL AND METHODS
3.1 Safety and Environment Risk Model (SERM)

SERM intend to address risks over the entire life of the complex system like IWT system where the risks are high or the potential for risk reduction is greatest [18].

Firstly, the goal base and risk base are determined in order to focus on the scope of the analysis. Then, it is important to know what the objectives of the study are. After that, the analysis is beginning with the Hazard Identification which involves qualitative and quantitative analysis. The analysis that used for qualitative study are such as Failure Modes and Effect Analysis, Fault Tree Analysis and also What-if Analysis. Then, the quantitative analysis involve on the reliability analysis such as the frequency analysis and consequences.

3.2 Qualitative Risk Assessment and Analysis Method

3.2.1 Hazard Identification (HAZID)

Hazard identification (HAZID) is the process of identifying hazards, which forms the essential first step of a risk assessment. There are two possible purposes in identifying hazards:

i. To obtain a list of hazards for subsequent evaluation using other risk assessment techniques. This is sometimes known as "failure case selection";

ii. To perform a qualitative evaluation of the significance of the hazards and the measures for reducing the risks from them. This is sometimes known as "hazard assessment".

During the hazard identification stage, the criteria used for the screening of the hazards will be established and possible hazards and accidents will be reviewed. Furthermore, the identified hazards was classified into critical and non-critical hazards. This failure case selection will be executed by generating check lists, accident and failure statistics, hazard and operability studies (HAZOPs) or by comparison with detailed studies and experience from previous projects.

3.2.2 Hazard and Operability Study (HAZOP)

Hazard and Operability (HAZOP) is a well known and well documented study. HAZOP is used as part of a Quantitative Risk Assessment (QRA) analysis. HAZOP is a more detailed review technique than HAZID. The purpose of the HAZOP was to investigate how the system from the design intent and create risk for personnel and equipment and operability problems. Identification of such deviations was facilitated by using sets of "guide words" as a systematic list of deviation perspectives. This approach is a unique feature of the HAZOP methodology that helps stimulate the imagination of team members when exploring potential deviations.

3.2.3 What if Analysis

"What-if" analysis is a creative brainstorming technique used for hazard identification, and qualitative risk assessment. It is designed to add structure to the intuitive and experimental expertise of persons with operational and practical experience. The discussions begins with the words 'What if', but other forms of initiating question may be 'How could', 'Is it possible' etc. It may be appropriate to pose all the questions in a brainstorming manner before trying to answer them. The

'What if' questions may include all relevant hazard and operational categories.

### 3.2.4   Fault Tree Analysis

Fault Tree Analysis uses tree structures to analyze system level failures into combinations of lower-level events, and Boolean gates to model their interactions. To address safetyand the ways failures or undesirable events could occur; and thereby, trying to avoid them can be very challenging.

The Boolean methodology and equations was used to construct and simplify the Fault Tree. As Fault trees are constructed, the Boolean equations are used to evaluate the Quantitative and Qualitative characteristic of a critical system.The Qualitative analysis of the Fault Tree determines the:

i.   probability of system failure (top event) based on a single failure (basic event) cause or common cause potential using minimal cut sets;

ii.   combination of component failures (minimal cut sets);

iii.   importance ranking of contributors to system failure. The Quantitative analysis of the Fault Tree focuses on the probabilities of system and cut set failure or the occurrence of the top event based on the probabilities of failure of the basic events.

The fault tree is a logic diagram based on the principle of multi-causality, which traces all branches of events which could contribute an accident or failure. It uses sets of symbols, labels and identifiers. The lists of symbols are shown below in Table 1.

Table 1: Fault tree analysis basic diagram.

Symbols	Descriptions
AND-Gate	Output exists only if all inputs exist
OR-Gate	Output exists if any one input exists
Basic event	Primary failure
Top event/intermediate event	Fault event usually resulting from more basic fault events

A fault tree diagram is drawn from top to down. The starting point is the undesired event of interest (called the 'top event'

because it gets placed at the top of the diagram). Then, we need to logically work out (and draw) the immediate contributory fault conditions leading to that event. These may each in turn be caused by other faults and so on.

3.2.5   Consequences Analysis

Consequence can be expressed as the number of people affected (injured or killed), property damaged, amount of spill, area affected, outage time, mission delay, dollars lost, etc. According to the measure chosen, the consequences were expressed "per event" [19].

Risks can have many potential impacts/consequences which can potentially affect many institutional objectives. Impacts/consequences can be expressed quantitatively through physical event modelling or extrapolation from experiments, studies or past data; or qualitatively as a descriptive representation of the likely potential outcome for each risk.

3.3 Quantitative Risk Assessment and Analysis Method

3.3.1   Frequency Analysis

Frequency analysis is used to predict how certain values of phenomenon may occur and to assess the reliability of the prediction. This frequency analysis gave the results of estimated data obtained from analysis and some from theoretical modelling. The calculation was done to calculate the anthropogenic noise energy budget per year.

i.   sound pressure level (p) to acoustic intensity

$$I = \frac{|P|^2}{\rho c} \quad \text{Watts/m}^2 \qquad (1)$$

ii.   account for the directionality of the source or calculate the power

$$P = A * I \qquad \text{Watts=Joules/se} \qquad (2)$$

iii.   energy per source transmission or ping (Eping), the acoustic power, multiplied by the duration of the transmission:

$$E_{per\ ping} = P * T_{ping} \qquad \text{Joules} \qquad (3)$$

iv.   number of source pings per year per source and the total number of sources in operation yield the annual energy budget for each source type:

$$E_{total} = E_{per\ ping} * N_{PINGS\ /\ YEAR} * N_{SOURCES} \qquad \text{Joules (4)}$$

The Table 2 below shows the data needed to calculate for the following energy budget of anthropogenic sound.

Next, for the case study, one investigation was done by previous studies to record the emissions of underwater noise sound from different types of boats that used in sampling activity at PulauBidong. Using the secondary data from that study, we calculated the total energy of anthropogenic sound for that different boat.

Table 2: Energy budget for anthropogenic sound.

sound source	Ping Dura-tion(s)	SPL dBre 1µPa@1m	Ping Energy (dB re 1µPa²*s)
underwater nu-clear explosion	8	328	337
airgun arrays	30	256	241
military sonar	6	235	243
Supertankers	continuous	185	
ship-shock trials	2	299	302
military sonar mid frequency	0.5	235	232
merchant vessel	continuous	132	
navigation sonar	1200	195	226
fishing vessels	continuous	151	
research sonar	120	195	226

Boat name	Boat type	Engine type, Horspow-er	Move-ment	RPM	Frequency range (kHz)
Discovery IV	Outboard	Mariner 2 unit x 90 Hp	Idle Medium speed High speed		1.1-4.3
Seroja	Inboard	Hino-EK 100 180 Hp	Idle Medium speed High speed	400 1200 1500	0.01-3.7
Discovery V	Outboard	Yamaha 40 Hp	Idle High speed		0.3-5.8
FASM I	Outboard	Yanmar 85 Hp	Idle High speed		0.01-5.9
Discovery IX	Inboard	Doosan 360 Hp	Idle Medium speed	700 1500	0.3-2.0

The anthropogenic noises were recorded for the noise of boats at PulauBidong, Terengganu. Experiment of boat noise from different distances was done using research vessel (Discovery II) as noise source at different distances 50m, 100m and 200m at coral reef area with constant speed 7 knot and 10m depth [13]. During the recordings, hydrophone sensor was placed in the water column about 1m to 2m depth from surface. The cable was held about 0.4m away from hull to minimize banging and slapping waves against the boat and also to avoid hydrophone from grazing boat wall. Each recording is done for one minute. The details for the boats are reported in the table 3.

Then, Poisson distribution equation was used to predict the number of successes will occur based on the number of ping per year emitted by the boats. The equation that used is as below:

$$P(X = k) \quad = \frac{\lambda^k e^{-\lambda}}{k!} \qquad (5)$$

where

e is Euler's number (e=2.71828…)
k! is the factorial of k
λ is the parameter or the expected value of X

Table 3: Types of control boats in the study.

3.3.2   Reliability Analysis

The reliability analysis for this study is involved the calculation of reliability based on the probability of Poisson distribution equation that used to predict the number of ping per year. The equation for calculate the reliability was as follow:

Reliability= 1-Probability (ping per year)   (6)

4. RESULTS AND DISCUSSION

4.1   Research outcomes

Researches outcome presented in this analysis are the results from qualitative and quantitative analysis. Fault Tree Analysis (FTA) and Failure Mode Effect Analysis (FMEA) are performed for the qualitative analysis. Meanwhile, the frequency analysis and consequences analysis are result for the quantitative analysis.

4.2   Safety and Environment Risk Model (SERM)

Safety and Environment Risk Model (SERM) address quantitatively, accident frequency and consequence of system. It intends to address risk over entire life of complex system where the risks are high or the potential for risk reduction is greatest [18]. This analysis model has determined how we implement the risk analysis to get the output for qualitative and quantitative analysis. The quantitative analysis is a result from frequency and consequences analysis that shows the secondary data from the previous study.

Meanwhile, qualitative analysis is done to search the factors that contribute to the underwater noise pollution. The results from the study shows that underwater noise pollution are caused by several factors such are shipping operations, de-

sign, onboard machinery, offshore activities, sonar, seismic survey, and other activities such as acoustic harassment. For the consequences analysis, the data are get from the results of "What if" analysis and Failure Modes and Effect Analysis (FMEA).

4.3 QUALITATIVE RISK ASSESSMENT AND ANALYSIS

4.3.1 Hazard Identification (HAZID)

The results from qualitative analysis had figured out the factors of underwater noise pollution. The factors are the outcomes from "What-if" Analysis and Failure Modes and Effect Analysis (FMEA). Some of the factors are shipping operation, onboard machinery, maintenance, seismic survey, sonar, offshore activities and other activities like acoustic harassment. The factors are determined and more investigation about the causes of the factors and also the mitigation methods to reduce the risk for these factors are implemented.

4.3.2 Hazard and Operability Study (HAZOP)

The outcome from Hazard and Operational Study is one of the results for qualitative analysis study. From the result, we can show that the ship speed contributes to a higher risk level than the other guidewords. Throughout the last century the shipping industry has seen a general trend of increases in total trade volume. So, we can conclude that sea are the busiest shipping road for all types of large ship such as container, bulk carrier, general cargo, passenger ships, fishing ships and many other ships. Ships are different in term of their speed and emit different level of underwater sound. Generally the shipping sound sources are comes from the motor, engine, propeller and vibration from the ship. It can cause masking or interference with echolocation and communication sound of marine mammals. The high speed vessels also can cause a higher potential for propeller's cavitations that cause higher frequency of underwater noise pollution emitted from the ships. This will cause the worst impacts towards marine animals. The results are shown in the Figure 1.
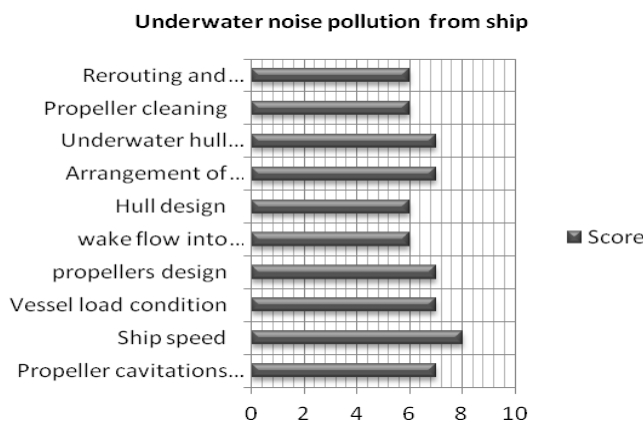

Figure 1: Underwater noise pollution from ships.

4.3.3 What-if Analysis

First, this "What-if" analysis study is done to investigate the causes of underwater noise pollution from ships and also anthropogenic noise which is man-made noise. The factors that have been analyzed in this study are design, onboard machinery, maintenance, offshore activities, seismic surveys, sonar, shipping operation and other activities such as acoustic harassment.

The results show the impact from the causes of underwater noise that may affect marine animals and also some recommendations in order to reduce that potential risk. There also given some evaluation for likelihood, impacts and total score for the risk that has been analyzed. When the total score is high, it means that factors are quite serious and need some immediate mitigation method to reduce or eliminate it. If not, it will give more serious impact towards marine animals.

Based on the risk studied, the score given as in the table above shows how seriousness the impact of that risk is. Figure 2 is constructed to compare the score level for each cause.
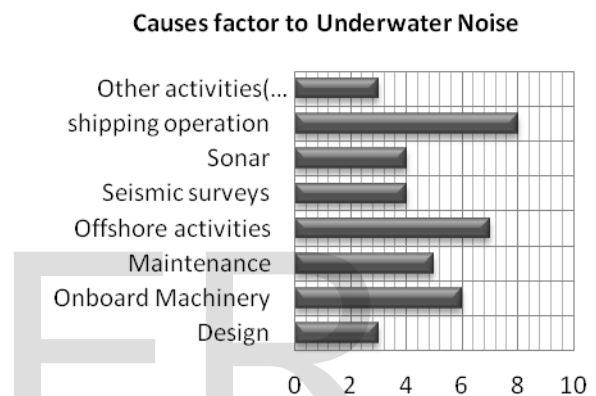

Figure 2: Causes factor to underwater noise pollution.

Referring the figure above, it shows that shipping operation, offshore activities, seismic surveys, and also maintenance are most factors that contribute to underwater noise pollutions. The score for shipping operation is 8, followed by offshore activities 7, and also seismic survey activities which is 6. The factors of shipping operation are cause by the ship sound and speed.

4.3.4 Fault Tree Analysis

Fault tree analysis is constructed because it is one of the analytical techniques for tracing the events which could contribute. For this analysis, FTA is done to determine the factors that cause the underwater noise pollution. From failure modes analysis that have been done, the factors of underwater noise pollution that have the highest risk are shipping operation, offshore activities, seismic survey, maintenance, and onboard machinery. Figure 3 and 4 below show the overall factors that cause underwater noise pollution from human activities.
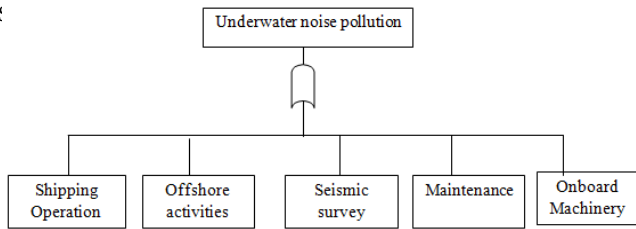
Figure 3: TOP event of Fault Tree Analysis.

For example, the minimal cut sets are calculated for shipping operation as below:

Shipping operation =(Design + wake flow) + (cavitation * high speed) + (Full load + ballast)

$$= (0.01+ 0.02) + (0.25*0.4) + (0.08 + 0.08)$$
$$= 0.03 + 0.1 + 0.160$$
P (shipping operation)   = 0.29
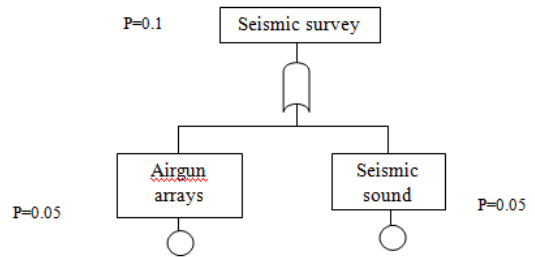
Figure 4: Fault three analysis.

Table 4: Probability of Fault Tree Analysis.

Element	Probability
Shipping operation	0.290
Offshore activities	0.141
Seismic survey	0.1
Onboard machinery	0.032
Maintenance	0.022
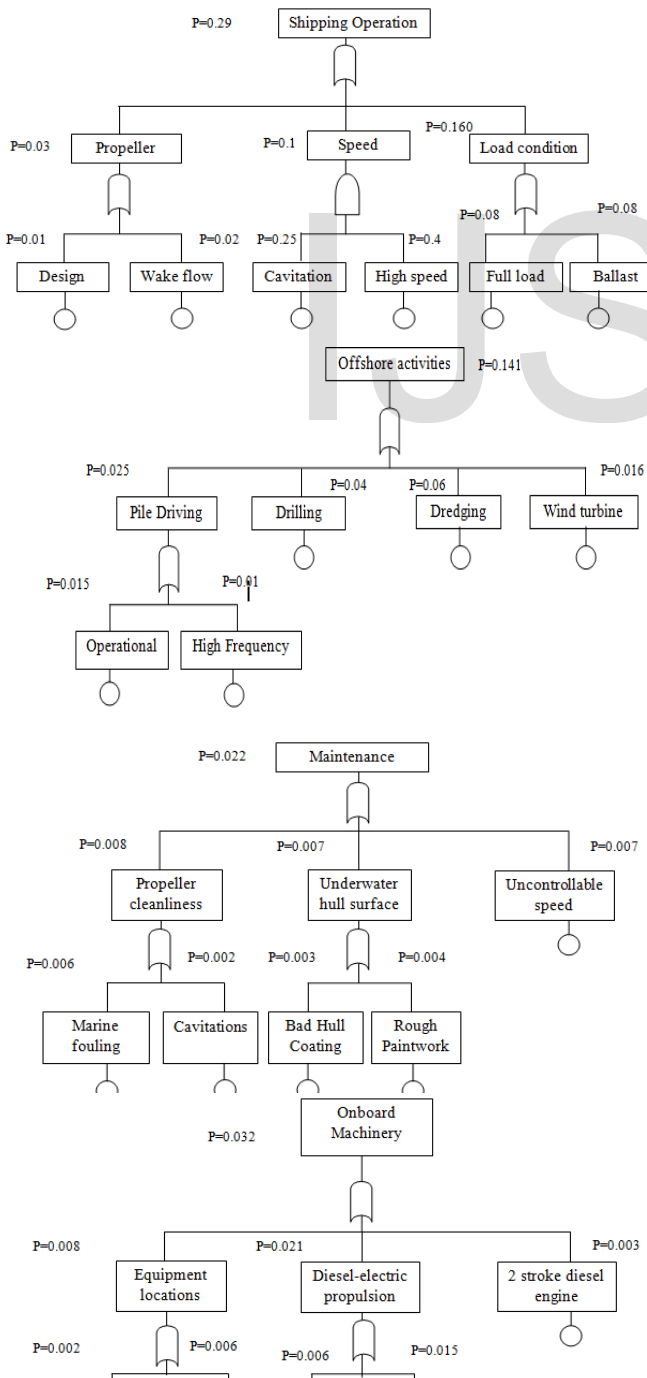
Based on the Table 4 above, the highest probability for the cause of underwater noise pollution is a shipping operation with the value 0.290. The total probability for the whole causes can be calculated using the equation below:

P (Cause) = P(shipping operation + Offshore activities + Seismic + Maintenance + Machinery)-(P $_{shipping\ operation}$. P $_{offshore\ activities}$. P$_{seismic}$. P$_{maintenance}$. P$_{machinery}$)

P (Cause)= (0.290 + 0.141 + 0.1 + 0.032 + 0.022) – (0.290 . 0.141 . 0.1 . 0.032 . 0.022)
    =0.584

4.3.5   Failure Modes and Effect Analysis

Based on Failure Mode and Effect Analysis, the result is constructed to analyze the risk associated with potential problems identified. The factors that cause underwater noise pollution are shipping operation, onboard machineries, design, maintenance, seismic survey, sonar, offshore activities and otherslike acoustic harassment.

Rating scales usually range from 1 to 5 or from 1 to 10, with the higher number representing the higher seriousness or risk. For example, on a ten point Occurrence scale, 10

indicate that the failure is very likely to occur and is worse than 1, which indicates that the failure is very unlikely to occur. Graph of Risk Priority Number (RPN) is plotted (Figure 5). After evaluation is made according to the frequency for each risk, it is observed that RPN and criticality prioritize causes differently. The value of RPN is calculated for the level of the potential causes of failure (Severity x Occurrence x Detection).

According to the RPN, "shipping" and "maintenance" are the first and second highest risks. The value of RPN for shipping is 216 and maintenance 168.
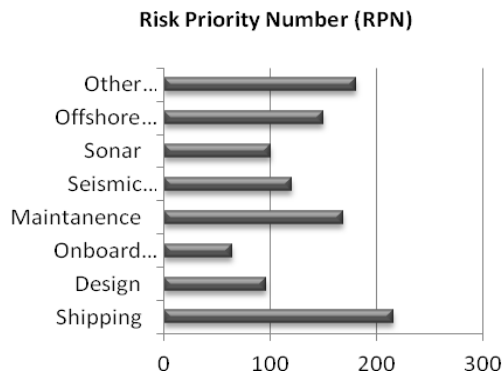

Figure 5: Risk Priority Number.

The value of Revised Risk Priority Number (RRPN) is also calculated from the FMEA. This provides an indication of the effectiveness of corrective actions and can also be used to evaluate the value to the organization of performing the FMEA.

The RRPN shows lower value compare to RPN because the risk has been control. For example of other activities which is for acoustic deterrent, the value of RPN is 120 because it can change the fish behaviour. Then, after monitoring and mitigation measure to detect, minimize or avoid potential adverse impacts as control for the risk, the value of RRPN become lower than RPN which is 8 (Figure 6).
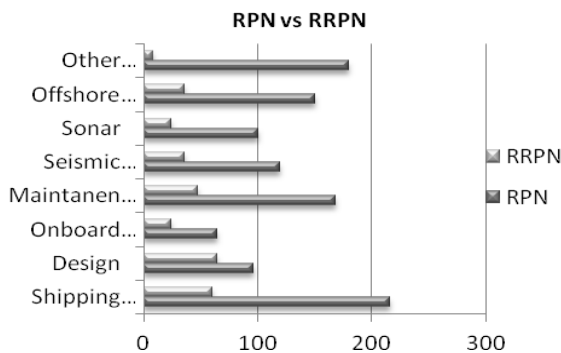

Figure 6: RPN vs RRPNN

4.3.6 Consequences Analysis

Risk matrix is constructed to show the level for eachrisk that obtained from qualitative analysis study. From the risk matrix, it shows that shipping operation is the highest

risk ranking. Speed of ship should be reduced in order to reduce the underwater noise emission from high speed of ships. If no mitigation or precautions steps are taken, it could give worst impact towards marine animals especially for their hearing and habitats (Figure 7).
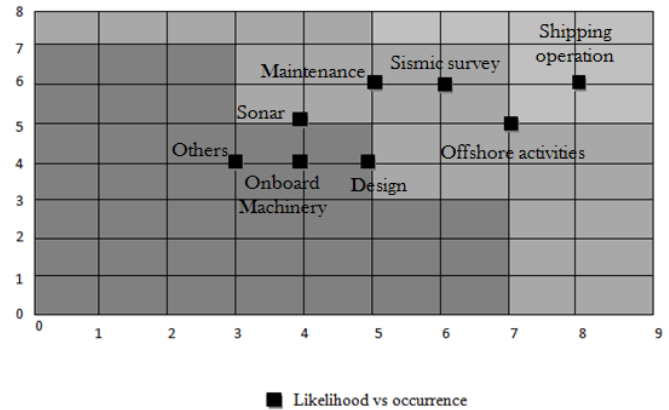

Figure 7: Risk Matrix Rating.

Underwater nuclear explosions, is top the annual anthropogenic energy budget with 2.1x 1015 Joules. Then, the most regularly operated sound sources are the airgun arrays for 80 days/year to produce 3.9 x 1013 Joules. Shipping contributes mostly from the largest vessels classes, with 11000 supertankers, operating 300 days/year to yield 3.7 x 1012 Joules. Energy budget per year is concluded as consequences of each source of anthropogenic noise. When the total energy is higher, then, it may give a serious impact towards marine animals. Underwater nuclear explosions can cause trauma or even death to marine animals.

A proposed annual energy budget of ping per year is presented in table above. Discovery V, is top the annual anthropogenic energy budget with 3.5x108 Joules with number of ping per year is 6. Then, the second ranking is the FASM I boats with energy budget ping per year of 7.6x107 Joules. The lowest anthropogenic energy budget is from Discovery IX with the value 1.9x105 Joules (Table 5).

Table 5: Total energy budget/ year for anthropogenic noise.

sound source	Intensity (dBre1W/m2)	power (dB re1W)	number of source	operate (days/year)	Repetition (pings/day)	Total energy (J)
under water nuclear explosion	146	157	1	0.05	1	2.1 x 1015
airgun arrays	61	66	90	80	4320	3.9 x 1013
military sonar	53	55	300	30	4320	2.6 x 1013
supertankers	3.2	11	11000	300	86400	3.7 x 1012
navigation sonar	-1.8	3.2	100,000	100	86400	3.6 x 1010
fishing vessels	-31	-23	25000	150	86400	1.7 x 109
research sonar	13	24	10	4	86400	9.1 x 108

4.4   Quantitative Risk Assessment and Analysis

4.4.1   Frequency Analysis

Frequency analysis is the calculation for the Poisson distribution for the case study in this analysis which is specific on UMT's boats, the value of Nping/year which is get from repetition (ping/day) x operate (days/year) is used as the value of λ.

The value of K is used of 1 which is equal to one year prediction.

The result shows that Discovery IV which has the number of 3 ping/year shows the highest probability for the possible eventoccurs in one year.

Then, it follows by Seroja with the probability value 0.07326 and 4 number of ping per year (Table 6).

Table 6: Probability ping per year for UMT boats.

Types	number of source	Repetition (ping/day)	Operate (days/year)	N ping/year	X=k (1 year)	P(x) Ping/year
Discovery IV	1	1	3	10	1	0.1494
Seroja	1	4	1	6	1	0.07326
Discovery V	1	2	3	6	1	0.01487
FASM I	1	2	3	4	1	0.01487
Discovery IX	1	2	5	3	1	0.000454

Discovery V and FASM I shows the same probability values which is 0.01487. The lowest value of the probability of boat for the possible event occurs in one year is Discovery IX which has 10 pings per year and the value of the probability is 0.000454. Discovery V, is the top annual anthropogenic energy budget with 3.5x108 Joules with number of ping per year is 6 (Table 7). Then, the second ranking is the FASM I boats with energy budget ping per year of 7.6x107 Joules (Table 8).

Table 7: Ping per year.

Types	number of source	Repetition (ping/day)	Operate (days/year)	N ping/year	X=k (1 year)	P(x) Ping/year
Discovery IV	1	1	3	10	1	0.1494
Seroja	1	4	1	6	1	0.07326
Discovery V	1	2	3	6	1	0.01487
FASM I	1	2	3	4	1	0.01487
Discovery IX	1	2	5	3	1	0.000454

Table 8: Energy budget per year for UMT boats.

Types	dB level	sound pressure level (µPa)	Intensity (W/m2)	Power (dB re 1W)	ping duration (s)	Energy per ping	Etoal(joules)
Discovery IV	34.31	30.71	46.6	58	2	117	3.5x106
Seroja	32.68	30.29	22	27	4.5	124	4.9x106
Discovery V	34.84	30.84	59.5	74	1.5	112	6.7x108
FASM I	34.71	30.81	56	70	1.8	126	7.6x107
Discovery IX	30.61	29.72	84.9	10	1.8	19	1.9x105

The lowest anthropogenic energy budget is from Discovery IX with the value 1.9x105 Joules (see Table 6).

4.4.2 Reliability Analysis

Table 9 below shows the results for the reliability analysis from the probability that has been calculation using Poisson distribution.

Table 9: Reliability analysis.

Types	P(x) Ping/year	Reliability= 1-P(ping/year)
Discovery IV	0.1494	0.8506
Seroja	0.07326	0.92674
Discovery V	0.01487	0.98513
FASM I	0.01487	0.98513
Discovery IX	0.000454	0.999546

According to the risk acceptability criteria, Discovery IV shows no serious impact towards marine animals because of the dB level is still in low frequency noise but the data is too small and limited for this study. So that, the prediction of the energy per ping of this Discovery IV maybe will increase for 10,100 and 1000 years in future. Cost maybe needed for the maintenance of the boat for antifouling and anti-corrosion work

5. CONCLUSION

The consequence from this risk study shows that underwater noise pollution can give serious impacts towards marine animals. It is currently not possible to derive assessment criteria with regard to underwater noise as there are too many uncertainties concerning how marine life perceives sound. Besides that, it shows that underwater noise pollution are caused by many causes such as shipping operation, design, offshore activities, onboard machineries and others. Shipping operations is the most critical element and contribute to the higher risk of underwater noise pollution. This outcome that expected from this research is to monitor and take mitigation methods in order to reduce or eliminate the high risk of the causes. Further studies are ongoing for the assessment of animal behavior and oxidative stress produced by noise pollution on gonadal and somatic tissues of various marine animals.

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NOMENCLATURE

A	=	Area
ALARP	=	As Low As Reasonable Practical
c	=	Speed
dB	=	Decibel
$E_{per\ ping}$	=	Energy per ping

E_{total} = Total energy

FMEA = Failure Modes and Effect Analysis

FTA = Fault Tree Analysis

HAZID = Hazard Identification

HAZOP = Hazard and Operability Study

Hz = Hertz

I = Acoustic Intensity

$N_{PINGS/YEAR}$ = Number of pings per year

$N_{SOURCES}$ = Number of sources

RPM = Revolution per minute

RPN = Risk Priority Number

RRPN = Revised Risk Priority Number

SERM = Safety and Environment Risk Model

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