Qualitative Risk Analysis Study of Offshore Aquaculture Ocean Plantation System

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Strictly as per the compliance and regulations of :

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Keywords : risk, reliability, offshore, aquaculture, algae, oceanic, farming.

I. Introduction

The technology, for very large floating structures has developed continually, while changing societal needs have resulted in many different applications of the technology for floating structure. Very large floating structure for offshore aquaculture of seaweed could be adapted TO offshore aquaculture ocean plantation system for oceanic farming of fish, prawn, squid and many more. The design of very large floating structure for offshore aquaculture ocean plantation system required a reliable and risk free system with robust mathematical and simulation, risk and reliability of the hydroelastic structure, mooring system, structure, and material. Hence, the study of risk and reliability for the mooring system of offshore aquaculture ocean plantation system is required to make sure the system can function well, be monitored, and accessed safety and efficiency. Typical mooring structure for offshore aquaculture include piers, docks, floats and buoys and their associated pilings, ramps, lifts and railways.

Mooring structure is required to follow local and international requirements for offshore standards, materials, installation timing and surveys. The mooring structures should; be able to withstand in critical saltwater and freshwater habitats when the standards, overwater structures shall be constructed to the minimum size necessary to meet the needs of ocean resources exploration use. Mooring system for VLFS need risk and reliability analysis of the associated criticality. Risk analysis of offshore aquaculture ocean plantation system focus on analyzing mooring structure with hope to help determine safe, reliability and efficiency of the system [3].

Qualitative assessment and quantitative risk assessment analysis methods are explored towards reliable decision support for VLFS. Qualitative assessment analysis employed qualitative tools like checklist, and HAZOP (Hazard and Operability Study) that define the system while quantitative risk analysis, the methods employed include Failure Modes and Effects Analysis (FMEA), Fault Tree Analysis (FTA), Risk Control Option based on HAZID (Hazard Identification) process. The risk of disaster cannot be eliminated, but risk can be reduced by employing better safety detection technique and establishing safety criteria prior to an accident occurrence. This paper describe development of simplified but holistic methodology that determine risk based decision support for reliable design and development of VLFS system, the risk analysis focus on mooring structure failure and reliability through employment of risk tools like FMEA, FTA, RCO and HAZID. The significant of this using risk method for VLFS are [1, 4]:

- To avoid system failure according recommendation from quantifying and deduction of improvement measures

- Identify inadequate mooring strength due to poor material quality of fatigue in order to determine required mitigation.

- Identified excessive environmental forces for example under estimated or freak environmental condition and determine solution for system additional uncertainty.

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- Predicted incorrectly mooring tension based on the reviews and analysis of the system.
- Perfumed risk and reliability leads to recommend the best safety level integrity of oceanic aquaculture seaweed plantation for mooring structure to alert the risk and improve reliability of this system.

The study involves conduct and determination the reliability analysis that can reduce the probability of accident risk occurrence and impact in offshore aquaculture system for ocean plantation. Especially mooring structure system integrity and reduction of consequence of failure. The study accesses the risk, system functionality and capability of offshore aquaculture seaweed plantation for mooring structure. The study also estimate the risk in design of mooring structure for deployment of very large floating structure for oceanic aquaculture seaweed plantation and decision recommendation will be offered for level integrity of oceanic aquaculture seaweed plantation for mooring structure.

II.   Algae Cultivation

Harvesting seaweed from wild population is an ancient practices dating back to the fourth and sixth centuries in Japan and China, respectively, but it was not until the mid-twentieth century that methods for major seaweed cultivation were developed. Seaweed has traditionally been grown in nearshore coastal waters, with some smaller operations on land. Offshore systems which are the focus of this study are an emerging seaweed culture technology. The seaweed extract, (Carrageenan) is an important hydrocolloids product for food additive ingredient and it is highly demanded in the world market. Seaweed is also used for biomass energy production as well as pharmaceutical and medicinal product The demand for seaweed has created huge market for this raw material, especially, the Cottonii seaweed also known as Kappaphycus (Euchema spp). For exemple, under the Malaysian Government NKEA, there is need to produce 1 million tonnes seaweed every year. Unfortunately, currently there is no proper system or platform to deliver this demand [14].

The mooring system failure analysis is very important part in the development offshore aquaculture ocean plantation system; risk analysis is required to determine the system function duty and performance. Besides that, there will be increasing demand for concept of floating technology worldwide, so the concept of offshore aquaculture ocean plantation system can be applied for the technology platform required. There is currently no systematic and formal proactive methodology for offshore aquaculture floating structure design. Offshore floating structure is required to be reliable in order to to withstand harsh environment.

A risk and reliability studies of offshore aquaculture system for mooring structure will contribute to sustainable development of the seaweed farming industry as well as improvement of technology platform for other aquaculture farming in open seas[2, 5].

III.   Risk and Reliability Analysis

Risk is defined as an objective, systematic, standardized and defensible method of assessing the likelihood of negative consequences occurring due to a proposed action or activity and the likely magnitude of those consequences, or, simply put; it is "science-based decision-making".   "Risk" is the potential for realization of unwanted, adverse consequences to human life, health, property or the environment. Its estimation involves both the likelihood (probability) of a negative event occurring as the result of a proposed action and the consequences that will result if it does happen. For example, in some sector, "Risk – means the likelihood of the occurrence and the likely magnitude of the consequences of an adverse event to public, aquatic animal or terrestrial animal health in the importing country during a specified time period." While some sectors incorporate consideration of potential benefits that may result from a "risk" being realized (e.g. financial risk analysis), others specifically exclude benefits from being taken into account. Risk analysis provides answer to the following questions: What can go wrong?, What are the chances that, it will go wrong? And what is the expected consequence if it does go wrong?

Risk is defined as the potential for loss as a result of a system failure, when assessing and evaluating uncertainties associated with an event, it can be measured as a pair of factors, one being the probability of occurrences of an event, also called a failure scenario, and the other being the potential outcome or consequence associated with the event's occurrence [1]. The definition of "risk" varies somewhat depending on the sector. Most definitions incorporate the concepts of:

i. uncertainty of outcome (of an action or situation),

ii. probability or likelihood (of an unwanted event occurring), and

iii. consequence or impact (if the unwanted event happens).

Risk assessment is the process used to determine the risk based on the likelihood and impact of an event. Failure history through experience (qualitative) and data (quantitative) may be used to perform a risk assessment [2]. Moreover, risk assessment is the determination of quantitative or qualitative value of risk related to a concrete situation and recognized threat.

Risk analysis is concerned with using available data to determine risk posed by safety hazards and

usually consists of steps such as scope definition, hazard identification and risk determination. The phase in which the decision process is inundated with metrics and judgments is called the risk evaluation. The purpose of analysis is to determine the contributory causes and circumstances of the accident as a basis for making recommendation, if any, with the aim of preventing similar accidents occurring again. "Risk analysis" is usually defined either by its components and/or its processes. The Society for Risk Analysis www.sera.org offers the following definitions of "risk analysis":

i. a detailed examination including risk assessment, risk evaluation and risk management alternatives, performed to understand the nature of unwanted, negative consequences to human life, health, property or the environment;

ii. an analytical process to provide information regarding undesirable events;

iii. the process of quantification of the probabilities and expected consequences for identified risks.

All risk analysis sectors involve the assessment of risk posed by a threat or "hazard". The definition of "hazard" depends on the sector and the perspective from which risk is viewed (e.g. risks to aquaculture or risks from aquaculture). A hazard thus can be:

i. a physical agent having the potential to cause harm, for example:

  a. a biological pathogen (pathogen risk analysis);

  b. an aquatic organism that is being introduced or transferred (genetic risk analysis, ecological risk analysis, invasive alien species risk analysis);

  c. a chemical, heavy metal or biological contaminant (human health and food safety risk analysis, environmental risk analysis); or

ii. the inherent capacity or property of a physical agent or situation to cause adverse effects, as in

iii. social risk analysis,

iv. financial risk analysis, and

v. environmental risk analysis.

Reliability analysis methods have been proposed in several studies as the primary tool to handle this category of risks [3]. Traditionally, the research and the development of reliability analysis methods have focused on generation and transmission. However, several studies have shown that most of the customer outrages depend on failures at the distribution level [4]. Furthermore, there is an international tendency towards adopt new performance based tariff regulation methods [5]. Hence, reliability of a system can be defined as the system's ability to fulfill its design functions for a specified time. This ability is commonly measured using probabilities. Reliability is, therefore, the probability that the complementary event that will occur will deads to failure. Based on this definition, reliability is one of the components of risk. Safety can be defined as the judgment of a risk's acceptability for the system safety, making to a component of risk management [1].

IV. Modeling Risk for Offshore Aquaculture Seaweed Farming

a) System Functionality and Standard Analysis

The analysis starts with system definition where input and output are highlighted. This followed by risk assessment, a risk assessment is the process used to determine the risk based on the likelihood and impact of an event. Failure history through experience (qualitative) and data (quantitative) may be used to perform a risk assessment (Glickman and Gough, 1993). Risk analysis is concerned with using available data to determine risk posed by safety hazards and usually consists of steps such as scope definition, hazard identification and risk determination. The phase in which the decision process is inundated with metrics and judgments is called the risk evaluation. The purpose of analysis is to determine the contributory causes and circumstances of the accident as a basis for making recommendation, if any, with the aim of preventing similar accidents occurring again.

b) Quantitative and Qualitative Risk Analysis

Qualitative analysis relies on statistical methods and databases that identify the probability and consequence. This objective approach examines the system in greater detail for risk [6]. Quantitative risk analysis generally provides a more uniform understanding among different individuals, but requires quality data for accurate results. Quantitative analysis involve introduction of science, holistic and sustainability approach to analyses and quantify risk. It leads necessary weightage to assist decision required for the system in question. There are many methods and technique that have been developed to perform various types of analysis, in areas such as reliability and safety. In order to perform risk assessment and analysis method, this can be determined by quantitative and qualitative risk analysis tools presented in Table 2 below.

Table 1 : Quantitative and qualitative risk analysis

Qualitative Methods
Checklist : Ensures that organizations are complying with standard practice.
Safety/Review Audit: Identify equipment conditions or operating procedures that could lead to a casualty or result in property damage or environment impacts.
What-If: Identify hazards, hazardous situations, or specific accident events that could lead to undesirable consequences.

Hazard and Operability Study (HAZOP): Identify system deviations and their causes that can lead to undesirable consequences and determine recommended actions to reduce the frequency and/or consequences of the deviations.
Preliminary Hazard Analysis (PrHA): Identify and prioritize hazards leading to undesirable consequences early in the life of a system. Determine recommended actions to reduce the frequency and/or consequences of prioritized hazards.
Quantitative Methods
Failure Modes and Effects Analysis (FMEA)   Identifies the components (equipment) failure modes and the impact on the surrounding components and the system.
Fault Tree Analysis (FTA)   Identify combinations of equipment failure and human errors that can result in an accident.
Event Tree Analysis (ETA)   Identify various consequences of events, both failures and successes that can lead to an accident.
Frequency Analysis
Consequence Analysis
ALARP: Possible to demonstrate that the cost involved in reducing the risk further would be grossly disproportionate to the benefit gained.
Cost Effectiveness Analysis

c) Reliability Analysis

Reliability analysis methods have been proposed in several studies as the primary tool to handle various category of risks (Billinton 2004; Janjic and Popovic 2007). Traditionally, the research and the development of reliability analysis methods have focused on generation and transmission (Kwok 1988). However, several studies have shown that most of the customer outrages depend on failures at the distribution level (Billinton and Allan 1996; Billinton and Sankarakrishnan 1994; Bertling, 2002). Furthermore, there is an international tendency towards adopt new performance based tariff regulation methods (Billinton 2004; Mielczarski 2006; Mielczarski 2005).

d) Risk Analysis in Maritime Industry

International Maritime Organization state that, Formal Safety Assessment (FSA) is a structured and systematic methodology, aimed at enhancing maritime safety, including protection of life, health, the marine environment and property, by using risk analysis and cost benefit assessment. FSA can be used as a tool to help in the evaluation of new regulations for maritime safety and protection of the marine environment or in making a comparison between existing and possibly improved regulations, with a view to achieving a balance between the various technical and operational issues, including the human element, and benefit between maritime safety or protection of the marine environment and costs. FSA consists of five steps which are, firstly is identification of hazards that means a list of all relevant accident scenarios with potential causes and outcomes, secondly is assessment of risks means that the evaluation of risk factors, thirdly is risk control options that is devising regulatory measures to control and reduce the identified risks, fourthly is cost benefit assessment which determining cost effectiveness of each risk control option and lastly recommendations for decision-making conclusion from the information about the hazards, their associated risks and the cost effectiveness of alternative risk control options.

e) The ALARP Principle

ALARP (As Low As Reasonably Practicable), is a used in the analysis of safety-critical and high-integrity systems. The ALARP principle define residual risk that shall be as low as reasonably practicable, it has been used for decision support for Nuclear Safety Justification, is derived from legal requirements in the UK's Health & Safety at Work Act 1974 and is explicitly defined in the Ionising Radiation Regulations, 1999. The ALARP principle is part of a safety culture philosophy and means that a risk is low enough that attempting to make it lower would actually be more costly than cost lkely to come from the risk itself. This is called a tolerable risk. The meaning and value of the ALARP tolerability risk presented in Figure 1 the triangle represents increasing levels of 'risk' for a particular hazardous activity, as we move from the bottom of the triangle towards the top".
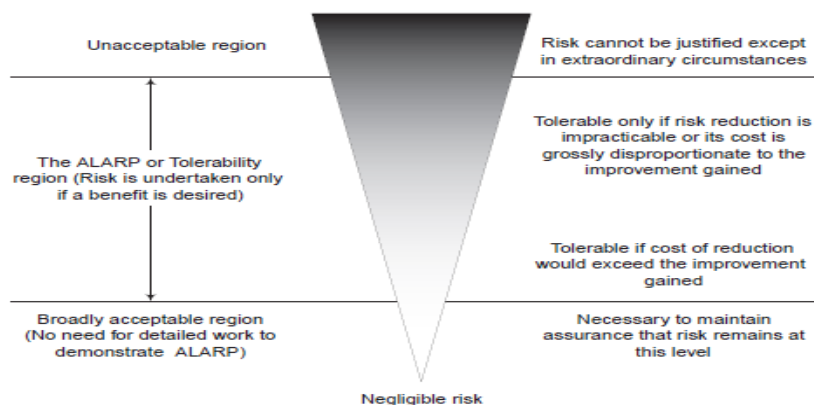
Figure 1 : Levels of Risk and As Low As Is Reasonably Practicable (ALARP)

f) Offshore Industry Risk Analysis

Traditionally, offshore quantitative risk analyses (QRAs) have had a rather crude analysis of barrier performance, emphasizing technical aspects related to consequence reducing systems. However, recently the Petroleum Safety Authority Norway (PSA) has been focusing on safety barriers and their performance, both in regulations concerning health, safety and environment (PSA, 2001) and in their supervisory activities. The development of offshore Quantitative Risk Assessment (QRA) has been lead by the mutual influence and interaction between the regulatory authorities for the UK and Norwegian waters as well as the oil companies operating in the work sea. Also, other countries have participated in this development, but to some extent this has often been based on the British and Norwegian initiatives according to DNV Consulting Support, GI 291, Det Norske Veitas AS, 1322 Hovik, Norway.

In more recent times, efforts to protect citizens and natural resources, has make governments to be more involved, requiring corporations to employ risk-reducing measures, secure certain types of insurance and even, in some cases, demonstrate that they can operate with an acceptable level of risk. During the 1980's and 1990's, more and more governmental agencies have required industry to apply risk assessment techniques. For instance, the U.S. Environmental Protection Agency requires new facilities to describe "worst case" and "expected" environmental release scenarios as part of the permitting process. Also, the United Kingdom requires submittal of "Safety Cases" which are intended to demonstrate the level of risk associated with each offshore oil and gas production facility (ABS Guidance Notes On Risk Assessment, 2000)

g) Offshore Rule for Offshore Structure

The variety of offshore structures concerning the function, size, geometrical configuration and material selection as well as the variability of the environmental factors complicate the development of a unique design

procedure (Research Centre Asia Classification Society, 2003). Therefore, the separate investigation of the interaction between the actual structure and the environment is necessary. For mooring system offshore rules (Bureau Veritas, 2010) use reference documents NI 493 "Classfication of Mooring System for Permanent Offshore Units". The design and specification of mooring structure for offshore aquaculture ocean plantation system must be based on all requirements had listed and mention in NI 493 document.

V. SAFETY AND RISK OF OFFSHORE AQUACULTURE

The EC–JRC International Workshop on ''Promotion of Technical Harmonization on Risk-Based Decision Making'' (Stresa/Ispra, May 2000) investigated the use of risk-based decision making across different industries and countries. Under the UK safety case regulations (UK Health and Safety Executive, 1992), each operator in the UK Sector is required to prepare a Safety Case for each of its installations, fixed or mobile, to demonstrate that [14];

i. The management system adequately covers all statutory requirements.

ii. There are proper arrangements for independent audit of the system;

iii. The risks of major accidents have been identified and assessed;

iv. Measures to reduce risks to people to the lowest level reasonably practicable have been taken;

v. Proper systems for emergency arrangements on evacuation, escape and rescue are in place.

Before an installation is allowed to operate, the Safety Case must be formally accepted by the Health and Safety Executive (HSE). Like any aquaculture industry, offshore aquaculture will benefit from thoughtful site selection. Offshore enterprises should be sited in areas that meet optimal biological criteria for

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species grow-out and minimize user conflicts with other established groups. Careful site selection may also ensure the development of offshore aquaculture zones or parks to expedite industry development.

a) Failure of Mooring System

It is clearly identified that mooring systems on Floating Production Systems are category 1 safety critical systems (Noble Denton Europe Limited, 2006). Multiple mooring line failure is required to put lives at risk both on the drifting unit and on surrounding installations. There is also a potential pollution risk. Research to date indicates that there is an imbalance between the critical nature of mooring systems and the attention which they receive.   The mooring system failure probability is considerably reduced with increases safety factor in particular for system with several parallel loads sharing element. For system with low overall safety factor, the mooring system failure probability is expected to increase with increasing in number of lines, whereas for high safety factors, the system failure probability is expected to reduce with the increasing number of lines. While for the same load distribution and number of lines, a wire system is in general more reliable than a chain system with the same overall safety factor [6].

Risk analysis is a process that provides a flexible framework within which the risks of adverse consequences resulting from a course of action can be evaluated in a systematic, science-based manner. Risk analysis is now widely applied in many fields that touch human daily lives and activities. These include decisions about risks due to chemical and physical stressors (natural disasters, climate change, contaminants in food and water, pollution etc.), biological stressors (human, plant and animal pathogens; plant and animal pests; invasive species, invasive genetic material), social and economic stressors (unemployment, financial losses, public security, including risk of terrorism), construction and engineering (building safety, fire safety, military applications) and business (project operations, insurance, litigation, credit, cost risk maintenance etc.). Risk analysis has wide applicability to aquaculture. So far, it has mainly been applied in assessing risks to society and the environment posed by hazards created by or associated with aquaculture development depending on aquaculture farming in question. The risks include risks of environmental degradation; introduction and spread of pathogens, pests and invasive species; genetic impacts; unsafe foods; and negative social and economic impacts.

b) Risk Framework

The general framework for risk analysis typically consists of four major components:

a. Hazard identification–the process of identifying hazards that could potentially produce consequences;

b. Risk assessment–the process of evaluating the likelihood that a potential hazard will be realized and estimating the biological, social, economic, environmental and failure consequences;

c. Risk management–the seeking of means to reduce either the likelihood or the consequences of it going wrong; and

d. Risk communication–the process by which stakeholders are consulted, information and opinions gathered and risk analysis results and management measures communicated.

c) Risk analysis process

The risk analysis process is a flexible process, Its structure and components vary and depend on the sector (e.g. technical, social or financial), the user (e.g. government, company or individual), the scale (e.g. international, local or entity-level) and the purpose (e.g. to gain understanding of the processes that determine risk or to form the basis for legal measures). It can be qualitative (probabilities of events happening expressed, for example, as high, medium or low) or quantitative (numerical probabilities). General idea of the risk and reliability analysis study of offshore aquaculture ocean plantation system focus on mooring structure of offshore aquaculture systems well as   investigation of the problem, goal and objectives, advantage, disadvantage, limitation, design for environment, data reliability. Analysis of historical information from various sources play important role in the outcome of system identification. Flow chart and tables and mathematical governing equation are used to present detail of the process and procedure. The outcome of risk leads to recommendation for system reliability of future work. This study process followed three tier, preliminary system identification, qualitative risk assessment that involve HAZID process and quantitative risk. The process of the approach is more elaborated as followed [7,9].

i. Preliminary system assessment and involve the review of past work data collection and general requirement for mooring structure. Data of analyses of offshore aquaculture ocean plantation mooring system and structure are collected in order to define system, deduce system risk areas and reliability areas.

ii. (HAZID) Hazard Identification qualitative process involves clarification risk. For risk analysis had two processes which are qualitative analysis and quantitative analysis. Qualitative assessment use HAZOP and checklist, Fault Modes and Effect Analysis (FMEA), Fault Tree Analysis (FTA).

iii. Quantitative analysis involves Analytical process that employed hybrid of deterministic, statistical, reliability and probabilistic method to redefine system behavior in the past, present and future.

These use of law physics, help to strength the analysis and support the study of the risk and reliability of this system.

iv. In result of each of the tier can lead to risk matrix, ALARP graph, Risk Control Option (RCO) and cost Effectiveness Analysis.

Since the design of VLFS for seaweed farming is required new methodology based on risk, guideline system for solving a problem with specific components such as phases, tasks, methods, technique and tools that are incoporated are (Irny, S.I. and Rose, A.A, 2005). It can define as follows:

i. "the analysis of the principles of method, rules, and postulates employed by a discipline",

ii. "the systematic study of methods that are, can be, or have been applied within a discipline",

iii. "the study of description of methods".

VI. Safety and Environmental Risk Model (serm)

SERM intend to address risk over the entire life of the complex system. SERM address quantitatively accidents frequency and consequences, as shown in Figure 1. SERM methology adapted from [9] intend to address risk over the entire life of the complex system. SERM address qualitative aspect as well quantitatively accidents frequency and consequences VLFS, as shown in Figure 2.
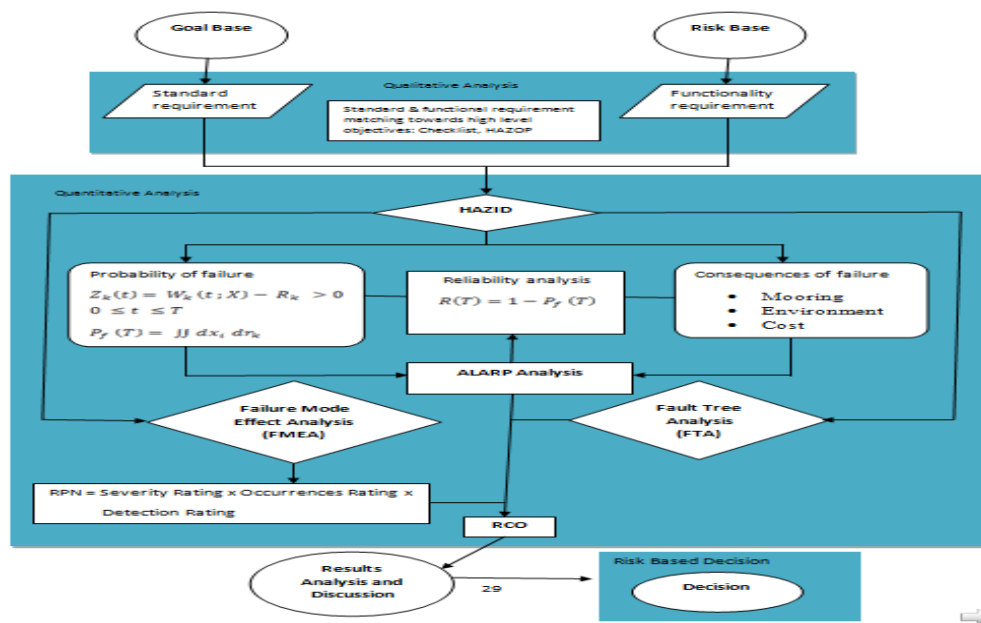

Figure 2 : SERM

a) Data Analysis

The raw collection data is obtained from specific places and method. The right sources should be chosen to make sure the data is reliable and valid for the study analysis. Some of the data will be obtained from model test, Meteorology Department, JPS (Jabatan Pengaliran dan Saliran), Offshore Company, Aquaculture Company and last but not least Seaweed Block System "SBS Project" in Setiu, Terengganu and Sabah.

b) Qualitative risk assessment and analysis method

i. Checklist

This is qualitative approach that to insure the organization are complying with standard practice. The checklist can be used as a preparation for system design, deployment, maintenance and monitoring to avoid unnecessary problems and delays. The checklist included in the International Safety Management (ISM) procedures as documentation about checks for

maintenance can be adopted for this study. The list can be filled in manually or printout electronically. Checklist analysis is a systematic evaluation against pre-established criteria in the form of one or more checklists. It is applicable for high-level or detailed-level analysis and is used primarily to provide structure for interviews, documentation reviews and field inspections of the system being analyzed. The technique generates qualitative lists of conformance and non-conformance determinations with recommendations for correcting non-conformances. Checklist analysis is frequently used as a supplement to or integral part of another method especially what-if analysis to address specific requirements. The quality of evaluation is determined primarily by the experience of people creating the checklists and the training of the checklist users [8].

ii. *Failure Modes and Effect Analysis (FMEA)*

A failure modes and effects analysis (FMEA) is a procedure in product development and operations management for analysis of potential failure modes within a system for classification by the severity and likelihood of the failures. A successful FMEA activity helps a team to identify potential failure modes based on past experience with similar products or processes, enabling the team to design those failures out of the system with the minimum of effort and resource expenditure, thereby reducing development time and costs. It is widely used in manufacturing industries in various phases of the product life cycle and is now increasingly finding use in the service industry. Failure modes are any errors or defects in a process, design, or item, especially those that affect the intended function of the product and or process, and can be potential or actual. Effects analysis refers to studying the consequences of those failures. The Figure 3 below shows the Risk Priority Number (RPN) methodology [10].
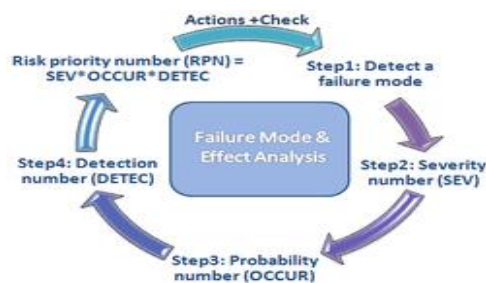

Figure 3 : Risk Priority Number

The RPN (Risk Priority Number) is the product of Severity, Occurrence and Detection (RPN = S x O x D), and is often used to determine the relative risk of a FMEA line item. In the past, RPN has been used to determine when to take action. RPN should not be used this way. RPN is a technique for analyzing the risk associated with potential problems identified during a Failure Mode and Effects Analysis. RPN = Severity Rating x Occurrences Rating x Detection Rating, is the formula used in FMEA.

iii. *Fault Tree Analysis (FTA)*

Fault tree analysis (FTA) is a top down, deductive failure analysis in which an undesired state of a system is analyzed using boolean logic to combine a series of lower-level events. This analysis method is mainly used in the field of safety engineering and Reliability engineering to determine the probability of a safety accident or a particular system level (functional) failure. In Aerospace the more general term "system Failure Condition" is used for the "undesired state" / Top event of the fault tree. These conditions are classified by the severity of their effects. The most severe conditions require the most extensive fault tree analysis. These "system Failure Conditions" and their classification are

often previously determined in the functional Hazard analysis. FTA can be used to:

i Understand the logic leading to the top event/ undesired state.

ii Show compliance with the (input) system safety/ reliability requirements.

iii Prioritize the contributors leading to the top event- Creating the Critical Equipment/Parts/Events lists for different importance measures.

iv Monitor and control the safety performance of the complex system (e.g. is it still safe to fly an Aircraft if fuel valve x is not "working"? For how long is it allowed to fly with this valve stuck closed?).

v Minimize and optimize resources. Assist in designing a system. The FTA can be used as a design tool that helps to create (output / lower level) requirements.

vi Function as a diagnostic tool to identify and correct causes of the top event. It can help with the creation of diagnostic manuals / processes.

Many different approaches can be used to model a FTA, but the most common and popular way can be summarized in a few steps. Remember that a fault tree is used to analyze a single fault event and that one and only one event can be analyzed during a single fault tree. Even though the "fault" may vary dramatically, a FTA follows the same procedure for an event, be it a delay of 0.25 msec for the generation of electrical power, or the random, unintended launch of an (Intercontinental Ballistic Missiles) ICBM.

c) *Quantitative risk assessment and analysis method*

A mooring device is failed when the mooring reaction force W, due to oscillation of the floating structure, exceeds the yield strength R. The floating structure drifts when all its mooring devices are failed. Failure of a mooring device indicates presence of an event satisfying the following condition:

$$Z_k(t) = W_k(t; X) > 0 \qquad 0 \le t \le T$$

where X is natural condition parameters, T duration of the natural condition parameters, and R_k the random variable for the final yield strength of mooring device k, X and R_k are independent of each other. The total reliability for years of service life is approximated by the following equation:

$$R_N(T) = (1 - P_f(T))^N$$

Failure probability for oscillation of the floating structure is

$$\left[M_{ij} + m_{ij}(\infty)\right]X(t)'' + F_v(X)' + \sum_{j=1}^{n} \int_{-\infty}^{t} \dot{x}_j(\tau)L_{ij}(t-\tau)d\tau$$
$$+ F_M(X,X) = F_{current}(t)' + F_1(t) + F_2(t)$$

where X: displacement vector of horizontal plane response of the floating structure; M_{ij} :inertia matrix of the floating structure; m_{ij} (∞): added mass matrix at the infinite frequency; F_v: viscous damping coefficient vector; L_{ij} : Memory influence function; F_M: Mooring reaction force vector; $F_{current}$: current load vector, F_1 and F_2: first and second current force vectors respectively. Estimation of wave force vector is generally expressed as the sum of linear wave force proportional to wave height and the slowly varying drift force proportional to the square of the wave height. See the equation below.

$$F (t) = F1 (t) + F2 (t)$$

$$= \int h_1 (\tau) \subset (t - \tau) \, d\tau + \iint h_2 (\tau_1, \tau_2) \subset (t - \tau_1) \subset (t - \tau_2) \, d\tau_1 \, d\tau_2$$

Where $h_1 (\tau)$ $h_2 (\tau_1, \tau_2)$ are the vectors of impulse response function of wave force. ζ (t) is the time series of surface elevation of incident waves. Current are considered the dominant impact factor to algae cultivation offshore, Static loads due current are separated into longitudinal load, lateral load. Flow mechanisms which influence these loads include main rope drag, main buoy drag, seaweed drag, and planting lines drag. The general equation used to determine lateral and longitudinal current load are:

$$F = \frac{1}{2} \rho V^2 A \, C_d$$

Floating structure and the pressure drag for the lateral walls. Average wind velocity distribution on the horizontal plane is assumed uniform. The velocity profile in the perpendicular direction expressed using the logarithmic rule. For the fluctuating wind velocity, the mainstream direction (average wind velocity direction) is the sole element of consideration [11].

VII. Assessment of Functional and Serviceability

Modern safety criteria for marine structures are expressed by limit states as indicate in the Table 2 below and are briefly outlined in the following. This will be applied to stages of risk and reliability assessment and analyzing the system required.

Table 2 : Safety Criteria (e.g. ISO 19900 1994, Moan 2004)

Limit State	Description	Remarks
Ultimate (ULS)	• Overall structure stability. • Ultimate strength of structure. • Ultimate strength of mooring system.	(Not relevant for VLFS) Component design check
Fatigue	• Failure of joint-normal welded joins in hull and mooring system.	Component design check depending on residual system strength after fatigue failure.
Accidental collapse (ALS)	• Ultimate capacity of damaged structure (due to fabrication defects or accident loads) or operational error.	System design check
Serviceability (SLS)	• Structure fails its serviceability if the criteria of the (SLS) are not met during the specified service life and with the required reliability	Disruption of normal use due to excessive deflection, deformation, motion or vibration.

The analysis on quantitative analysis is progress; the analysis is done to obtain probability of exceedance, system and mooring reaction relative to annual maximum current velocity, extreme wave return period, maximum mooring force and strength while the reliability will determined the mean current, conditional probability of failure and eventual determination of variation of failure probability and acceptable number of mooring required for the system [12].

VIII. Cost Analysis

Risk control measures are used to group risk into a limited number of well practical regulatory and capability options. Risk Control Option (RCO) aimed to achieve (David, 1996):

i. Preventive: reduce probability of occurrence

ii. Mitigation: reduce severity of consequence

Total cost = present value of future cost + Cost of protective measure

(Cc) = Co +Cc

The cost effective risk reduction measures should be sought in all areas. It is represented by followed:

Acceptable quotient = Benefit/ (Risk /Cost)

IX. Result and Discussion

a) Preliminary Hazard Analysis

Risk analysis is less commonly used to achieve successful and sustainable aquaculture by assessing the risks to aquaculture posed by the physical, social and economic environment in which it takes place.

Table in appendix provide general risk for aquaculture, this include environmental risks (e.g. due to poor siting or severe weather events), biological risks (infection by pathogens via transfer from native stocks, predation by seals and sharks; red tides etc.), operational risks (poor planning, work-related injuries), financial risks (e.g. market changes, currency fluctuations, emergence of new competitors, etc.) and social risks (negative image and resulting product boycott, lack of skilled manpower, competition from other sectors). Table given in the appendix represent result of preliminary hazard analysis whose matrix is given in Figure.

3.1 Checklist

Table 3 : Risk to the System

	Potential Risk	Likelihood L-M-H	Impact L-M-H	Score 1-10	Measures required to control risk
1) Anchor and Mooring System					
• Corner buoy • Position anchor • Position sinker • Adjustment anchor • Adjustment outer sinker • Corner mooring rope • Position mooring rope • Adjustment mooring rope • Position buoy • Adjustment buoy	• Fatigue • Failure • Sink Collapsed • Damage • Corrosion (internal or external) • Decayed • Destroy by surrounding • Unsuitable materials • Unsuitable size • Not enough number of anchor, buoy, or sinker	H	H	9	• Use fabricate concrete block for the anchors. • Use fabricates drum shape concrete for sinkers. • Use PE rope (uv resistant) for ropes. • Use A3 inflatable buoy (60 kg buoyancy) for medium buoy or A1 inflatable buoy (15 kg buoyancy) for small buoy.
2) Frame and Boundary					
• Frame rope • Boundary rope • End boundary rope	• Inadequate rope • Break • Fatigue • Unsuitable frame design	M	M	6	• Inhouse design, fabricate rope with floats and loops. • Use PE rope (uv resistant) for ropes.
3) Buoy					
• Corner buoy (large) • Intermediate buoy (medium)	• The size and buoyancy.	H	H	8	• Use A5 inflatable buoy (180kg) for large buoy and A3 inflatable buoy (60 kg) for medium buoy.
4) Connector					
• Buoy shackle (XL) • Sinker shackle (M) • Line shackle (M) • Boundary sinker shackle (M)	• Types of connector • The uses of them • Loss • Hard to get • Maintenance	L	L	3	• Use stainless steel shackle. • Used as a connecting link in all manner of rigging systems.
5) Planting Line					
• Planting rope • Web rope • Clipper • Adjustment buoy	• Loose • Slack rope • Too heavy • Cannot float • Arrangement	M	M	7	• Inhouse design, fabricate rope with floats and inserted planting twine • Use connection rope. • Use stainless steel clipper. • Use Molded float (20kg buoyancy)

6) Floating Platform					
• Platform • Position anchor • Mooring rope • Adjustment buoys • Sinkers	• High cost • Unnecessary • Collapsed • Need more people to work	L	L	3	• 15 mt timber, 300 used drum, steel room with canvas, wind/solar power set. • Use PE rope (uv resistant). • Use A3 inflatable buoy (60kg buoyancy). • Fabricate drum shape concrete.
7) Environment					
• Wind • Wave • Current • Speed direction • Type of soil • Tide level • Depth of sand • Seabed	• Including normal to extreme wind • The wave height • The maximum speed of the current • The direction of speed came from • The highest tide and the low tide • Type of soil underneath the sea • The maximum depth of sand layer • Rocky seabed, debris in the seabed, exposed sharp edge	H	H	9	• Design the best system can withstand all types of condition. • Analysis the system before applies it. • Do a test as many as could until the maximum force that the system can stay.
8) Design					
• Inappropriate design • Configuration • Structure • Structural integrity	• Poorly designed, constructed and maintained farms are more likely to pose a hazard to navigational safety. • The shape, system, components can it hold the system • Failure • Fatigue • Collapsed • Corrosion • Incompatible between the system • Connection	H	H	9	• Have alternative design. • Have connection. • Each component and system must have their own uses. • Full detailed. • Have interaction between each component and system.
9) Cost					
• Deployment (system, platform) • Transporter (PVC pipe raft, outboard engine) • Theft • Predator	• High cost (PVC pipe and accessories, dyneema line, wood platform and workmanship) • Maintenance • Overcome the lost • Uncontrollable	L	L	2	• Sea deployment cost. • Avoid from human being want to steal the seaweed. • Avoid treat from turtle or any animals that eat seaweed.

10) Location						
▪ Setiu, Terengganu	▪ The incorrect positioning of this system can increase their potential as a navigational hazard both through their geographical positioning with regard to other users of marine areas, and their physical positioning and size with respect to currents and sea states	H	H	8	▪ Site visit. ▪ Do research and analysis.	
11) Natural Disaster						
▪ Tsunami ▪ Swirl ▪ Hurricane ▪ Heat Wave	▪ The natural disaster is unpredictable, when occurs may collapsed all system	L	L	1	▪ Cannot change anything when they happen. ▪ Backup plan.	
12) Pollution						
▪ Water pollution	▪ May the system effect /harm the sea water	L	L	1	▪ Totally could not harm the sea water. ▪ 100% environmental friendly	
13) Seaweed						
▪ Long lasting ▪ Suitable type	▪ Can stand long time in sea water. ▪ The right type of seaweed that have many functions and give benefits	L	L	2	▪ Multi-functions purpose. ▪ Suggested type of seaweed.	
14) Human						
▪ Error ▪ Failure	▪ Installation ▪ Procedure to farm the seaweed ▪ Inconsistency	M	M	7	▪ Certificate crew. ▪ Competence crew.	
15) GHG						
▪ Global warming	▪ Release the greenhouse gas	L	L	3	▪ Check with methodology department.	
16) Manual						
▪ System	▪ Always take a look the system, site visit	L	L	3	▪ Certificate crew. ▪ Competence crew.	
17) Operation						
▪ The system cannot function	▪ Make sure the system is function	M	M	7	▪ Certificate crew. ▪ Competence crew.	

Table 4 : Risk from the System To The Outside

	Potential Risk	Likelihood L-M-H	Impact L-M-H	Score 1-10	Measures required to control risk
1) Ecology					
▪ Habitat ▪ Organism	▪ May affect the ecosystem of living organism under sea water	L	L	9	▪ Research what type of organism living under sea water.
2) Passing vessel/ Navigation					
▪ Ships ▪ Ferries ▪ Fishing boats	▪ Disturb the sea traffic	H	H	9	▪ Link with Marine Department to know the scheduled.
3) Health					
▪ Medicine	▪ Good for supplement ▪ People use to cure sickness and disease	M	M	6	▪ Benefit to community.
4) Human					
▪ Systematic system for human	▪ Easy to farm seaweed in a proper way ▪ More seaweed we farm	H	H	10	▪ Can supply the raw material to the government.

b) Fault Mode and Effects Analysis

According to FMEA analysis the top potential modes for this system after we define are anchor and mooring system, environment, design, cost, buoy and location. For anchor and mooring system requirement, the severity almost reaches the highest mark which is 9 marks, but for occurrence and detection they are 8 and 7 marks respectively. That brings 504 Risk Priority Numbers.

Table 5 : FMEA

...nents	Potential Failure Mode	Potential Effects of Failure	Severity (1-10)	Potential Cause(s) of Failure	Occurrence (1-10)	Current Controls	Detection	Risk Priority Number (RPN)	Recommended Action	Revised Severity (1-10)	Revised Occurrence (1-10)	Revised Detection (1-10)	Revised Risk Priority Number
...d	▪ Corner buoy ▪ Position anchor ▪ Position sinker ▪ Adjustment anchor ▪ Adjustment outer sinker ▪ Corner mooring rope ▪ Position mooring rope ▪ Adjustment mooring rope ▪ Position buoy ▪ Adjustment buoy	▪ Fatigue ▪ Failure ▪ Sink Collapsed ▪ Damage ▪ Corrosion (internal or external) ▪ Decayed ▪ Destroy by surrounding ▪ Unsuitable materials ▪ Unsuitable size ▪ Not enough number of anchor, buoy, or sinker	9	• Environmental loading • Wrong position buoy • Wrong position anchor • External forces • Wrong design • Estimation of the mooring	8	▪ Use fabricate concrete block for the anchors. ▪ Use fabricates drum shape concrete for sinkers. ▪ Use PE rope (uv resistant) for ropes. ▪ Use A3 inflatable buoy (60 kg buoyancy) for medium buoy or A1 inflatable buoy (15 kg buoyancy) for small buoy.	7	504	• Choose the suitable material and high quality to prevent any unwanted accidents or failure occurs.	5	5	4	100

For environment requirement, like wave, wind, current, and seabed the severity number is 9 marks same with detection and the occurrence is 8 marks. So, the RPN is 648. Furthermore, for design requirement for example the inappropriate design, configuration, structure integrity make the severity number is 9 marks share the marks with detection while occurrence is 8 marks, from that, the RPN is 648 same with environment. Moreover, the costs also contribute the biggest potential modes for this system like system deployment. The severity number for the cost is 9 marks, the occurrence is 8 marks and the detection is 7 marks, that make the RPN is 504. Besides that, for buoy and location requirements are also very important. For buoy like corner buoy and intermediate buoy make the severity number is 8, the occurrence number is 7 and detection number is also 8 marks. So the RPN is 448. Meanwhile, the selection for the location is playing the strong point. For the severity it achieves 8 marks same with occurrence, and the detection is 7 marks. From that, the RPN is 448. There are also having another potential modes failure for example frame and boundary, connector, planting line, floating platform, natural disaster, pollution, seaweed, human, manual, operation, ecology, passing vessel or navigations and health. But, they only score medium and low marks for severity, occurrence and detection. As summarize, the most potential modes failure are environment and design. While anchor and mooring system with cost below them and followed by location and buoy. From that, in quantitative analysis we focus more on environment, cost and mooring system. Table 5 show risk matrix for likelihood (from checklist) and severity (FMEA).

Table 5 : Risk Matrix

Risk Rating = Likelihood x Severity

Risk Rating		Severity (FMEA)									
		1	2	3	4	5	6	7	8	9	10
Likelihood(Cheklist)	10	10	20	30	40	50	60	70	80	90	100
	9	9	18	27	36	45	54	63	72	81	90
	8	8	16	24	32	40	48	56	64	72	80
	7	7	14	21	28	35	42	49	56	63	70
	6	6	12	18	24	30	36	42	48	54	60
	5	5	10	15	20	25	30	35	40	45	50
	4	4	8	12	16	20	24	28	32	36	40
	3	3	6	9	12	15	18	21	24	27	30
	2	2	4	6	8	10	12	14	16	18	20
	1	1	2	3	4	5	6	7	8	9	10

Likelihood   *   Severity

0-2 Zero to very low   0-2 No injury or illness

3-4 Very unlikely   3-4 First aid injury or illness

5-6 Unlikely   5-6 Minor injury or illness

7-8 Likely   7-8 "Three day" injury or illness

9-10 Very Likely   9-10 Major injury or illness

Score Action to be taken

0-16   No further action needed.

20-36   Appropriate additional control measures should be implemented

42-100   Work should not be started or should cease until appropriate additional control measures are implemented
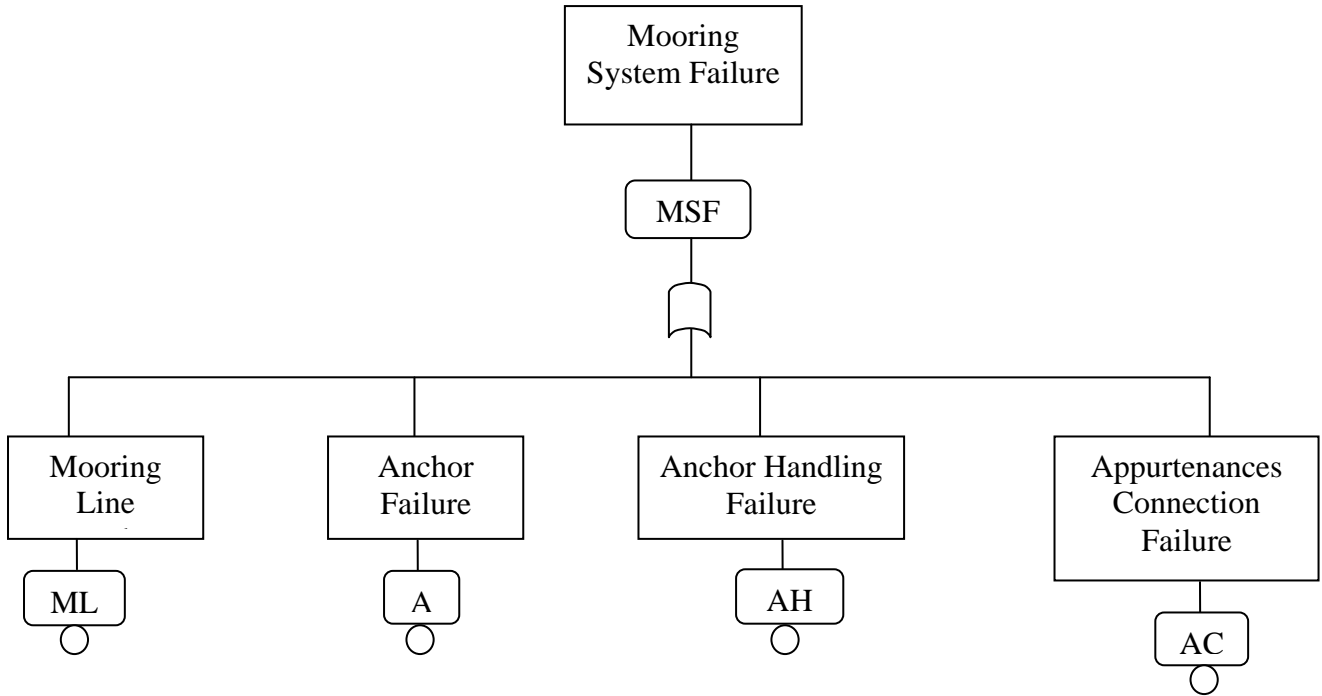
c) *Fault Tree Analysis*

Figure 4 : FTA

MSF = MLB ∪ AF ∪ AHF ∪ ACF
= MLB + AF + AHF + ACF

Table 6 : The cut set of MLB

Rank	Cut Set	Order	Important Level
1	EWa, EWi, ECu	3rd	0.037
2	AEC	1st	0.003
3	NH	1st	0.0023
4	HE	1st	0.0009
5	EF	1st	0.0006
6	MF	1st	0.0006
7	UC	1st	0.0004
8	IC	1st	0.0004
9	ESE	1st	0.0001
10	RS, DiS	2nd	0.0000027
Probability of MLB			0.0453027

Table 7 : The cut set of AF

Rank	Cut Set	Order	Important Level
1	EWa, EWi, ECu	3rd	0.037
2	AEC	1st	0.003
3	NH	1st	0.0023
4	HE	1st	0.0009
5	EF	1st	0.0006
6	MF	1st	0.0006
7	DE	1st	0.0005
8	UC	1st	0.0004
9	IC	1st	0.0004
10	IQC, PRM	2nd	0.0000015
Probability of AF			0.0457015

Table 8 : The cut set of AHF

Rank	Cut Set	Order	Important Level
1	EFoW	1st	0.004
2	IWMS	1st	0.004
3	UAM	1st	0.003
4	HE	1st	0.0009
5	DE	1st	0.0005
6	IC	1st	0.0004
7	UC	1st	0.0004
Probability of AHF			0.0132

Table 9 : The cut set of ACF

Rank	Cut Set	Order	Important Level
1	EWa, EWi, ECu	3rd	0.037
2	AEC	1st	0.003
3	HE	1st	0.0009
4	IDC	1st	0.0007
5	IMS	1st	0.0005
6	UC	1st	0.0004
7	UE	1st	0.0004
8	IC	1st	0.0004
9	WM	1st	0.0003
10	ME	1st	0.0002
Probability of ACF			0.0438

Minimal cut expression for the top event

$$T = C_1 + C_2 + C_3 + ... + C_N$$
$$T = C_{AF} + C_{MLB} + C_{ACF} + C_{AHF}$$
$$= 0.0457015 + 0.0450327 + 0.0438 + 0.0132$$
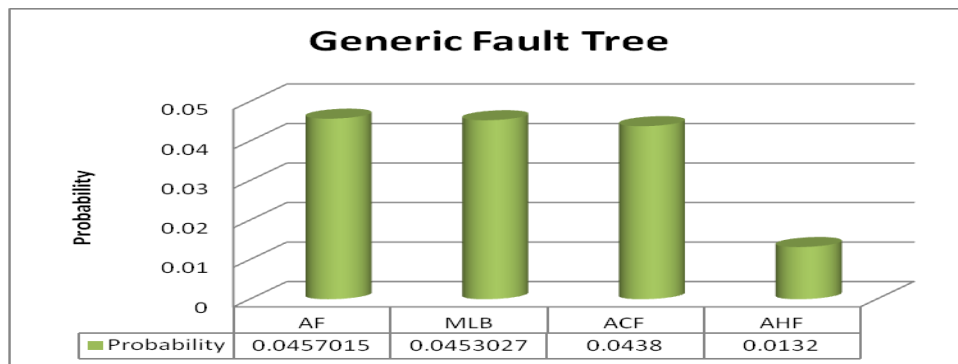$$= 0.1480042 \text{ per year.}$$

Figure 5 : Fault three analysis summary

From the calculation of minimal cut set it is found that the probability of top event mooring system failure is 0.1480042 per year, in terms of frequency index it is classified as reasonably probable. The graph shows the most critical event in mooring system failure is due to anchor failure (AF) with the probability 0.0457015 per year. The second critical event is mooring line break (MLB) 0.0453027 per year, followed by appurtenances connection failure (ACF) 0.0438 per year, and anchor handling failure with probability (AHF) 0.0132 per year.

X. CONCLUSION

An integrated approach to risk analysis will assist the aquaculture sector in reducing risks to successful operations from both internal and external hazards and can similarly help to protect the environment, society and other resource users from adverse and often unpredicted impacts. This could lead to improved profitability and sustainability of the sector, while at the same time improving the public's perception

of aquaculture as a responsible, sustainable and environmentally friendly activity. There exists, considerable scope to develop and expand the use of risk analysis for the benefit of aquaculture and the social and physical environments in which it takes place. Design based on risk continue to be a best practice in many industry such as offshore, nuclear, airline, power plant and others where occurrence of accident is unacceptable. Offshore platform design has been successful because of risk approach to design. The maritime industry has adopted risk based design for reliability of marine system in order avoids accident that can lead to Loss of life Loss of property, Loss of money and Destruction of environment. The result of quantitative risk will be provided in other paper. The quantitative risk analyze the risk, system functionality and capability of offshore aquaculture for seaweed plantation for mooring structure and also estimate the risk in design mooring structure and deployment of very large floating structure for oceanic aquaculture seaweed plantation.

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APPENDIX

Societal risk imposed from aquaculture

Environmental risks	Biological risks	Financial risks	Safety
• pollution from feeds, drugs, chemicals, wastes • alteration of water currents & flow patterns	• introduction of invasive alien species, exotic pests & pathogens • genetic impacts on native stocks • destruction/modification of ecosystems and agricultural lands (mangrove deforestation, salination of ricelands)	• failure of farming operations • collapse of local industry/sector Social risks • displacement of artisanal fishers Human health risks • food safety issues	Mooring failure Risk

Table : Risks to aquaculture from society and the environment

Environmental risks	Biological risks	Operational risks	Financial risks	Social risk
• severe weather patterns • pollution (e.g. agricultural chemicals, oil spills)	• pathogen transfer from wild stocks • Local predators (seals, sharks etc.) • toxic algal blooms, red tide	• poor planning • poor design • workplace injuries	• market changes • inadequate financing • currency fluctuations • emergence of new competitors	• negative image/press • lack of skilled manpower • competition for key resources from other Sectors •theft, vandalism