Risk and Hazard Operability Process of Deep Water Marine System

A.H. Saharuddin, O. O. Sulaiman and A.S.A. Kader

Abstract—**The maritime and offshore industry has made use of the ocean in a very responsible way, the challenged posed by environmental concern in the coastline is evolving new technology and new ways for technological development. In an age so dire to find alternative and sensitive ways to mitigate challenge of global warming, climate changes and its associated impact, maritime and offshore activities is loaded with requirement to build new sustainable and reliable technology for deep sea operation in order to fulfil alternative mitigation options for climate change, decline of coastline resources and enthophication. Expanding deep sea operation require development of technology related to dynamic position, mobile berthing facilities, collision aversion, impact of new environment, wave, wind on marine structure, supply vessel operation and fact that coastal water transportation attracts low probability and high consequence accidents. This makes reliability requirements for the design and operability for safety and environmental protection very necessary. This paper discusses process work in risk, hazard and reliability based design and safe and efficient operability deep water operation waters. This includes a system based approach that covers proactive risk as well as holistic multi criteria assessment of required variables to deduce mitigation options and decision support for preventive, protective and control measures of risk of hazard for deep water marine offshore operation.**

Index Terms— **Risk, Reliability, Safety, Environment, Deepwater, Marine**

I. INTRODUCTION

Offshore operation and marine transportation service provide substantial support to various human activities; its importance has long been recognized. The clear cut advantage of inland transportation over other modes of transportation, short sea service and evolving deep sea activities are being driven by recent environmental problems and dialogues over alternative renewable ways of doing things. The criticality of offshore and marine transportation operations within the coastline and the prohibitive nature of the occurrence of accidents due to high consequence and losses have equally made it imperative and necessary to design operate and maintain sustainable, efficient and reliable deepwater offshore operation and marine transportation systems. Marine accidents fall under the scenarios of collision, fire and explosion, flooding, and grounding. This paper discusses a model of reliability for the assessment and analysis of marine accident scenarios leading to design for the prevention and protection of the environment. The paper will address risk process that can optimize design, existing practice, and facilitate decision support for policy accommodation for evolving offshore deepwater regime [1], [2].

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II. RISK RELIABILITY MODELLING REQUIREMENT

In order to build reliable deep water offshore system and supporting transportation system, it is important to understand the need analysis through examination of the components of system functionality and capability. This functionality capability of the platform, environmental loading and other support system environmental risk as well as ageing factors related to design, operation, construction, maintenance, economic, social, and disposal requirement for sustainable marine system need to be critically analysed. Risk identification work should be followed by risk analysis that include risk ranking, limit acceptability and generation of best options towards development of safety and environmental risk mitigation and goal based objective for evaluation of the development of sustainable cost effective inland water transportation that fall under new generation green technology [3], [8]. Weighing of deductive balancing work requirement for reliable and safety through iterative components of all elements involved should include social, economic, health, ecological and technological considerations. Other concerns are related to other uses of water resources and through best practice of sediment disposal, mitigation for environmental impact, continuous management, monitoring, and compensation for uncertainty as well as preparation for future regulation beyond compliance policy or principles.

Risk assessment has been used by the business community and government, and safety cases of risk assessment have been used by United Kingdom (UK) health safety and environment (HSE). In the maritime industry, risk assessment has been used for vessel safety, marine structure, transportation of liquefied natural gas (LNG), and offshore platforms. In Europe maritime risk assessment has been used for coastal port risk analyses and pilot fatigue. International Maritime Organization (IMO) and United State Coast Guard (USCG) rule making have issued guidelines and procedures for risk based decision making, analysis and management under formal safety assessment [4], [12]. Risk analysis when used for rulemaking is called Formal Safety Assessment (FSA), while when it is used for compliance is addressed as Quantitative Risk Analysis (QRA). Contemporary time has seen risk assessment optimization using scenario based assessments, which considered the relative risks of different conditions and events. In the maritime industry, contemporary time risk assessment has been instrumental to make reliable decisions related to prediction of flood, structural reliability, intact stability, collision, grounding and fire safety. Probabilistic and stochastic risk assessment and concurrent use of virtual reality simulation that considers the broader impacts of events, conditions, scenarios on geographical, temporal impacts, risks of conditions is important to for continuous system monitoring. Additionally, sensitivity and contingency (what if) analyses can be selectively used as tools to deal with remnant reliability and uncertainty that answer hidden questions in dynamic and complex systems [13].

III. System Failure and Risk Based Design Requirement for Deep Water System

A basic principle for risk-based design has been formulated: the larger the losses from failure of a component, the smaller the upper bound of its hazard rate, the larger the required minimum reliability level from the component. A generalized version and analytical expression for this important principle have also been formulated for multiple failure modes. It is argued that the traditional approach based on a risk matrix is suitable only for single failure modes/scenarios. In the case of multiple failure modes (scenarios), the individual risks should be aggregated and compared with the maximum tolerable risk. In this respect, a new method for risk-based design is proposed, based on limiting the probability of system failure below a maximal acceptable level at a minimum total cost (the sum of the cost for building the system and the risk of failure). The essence of the method can be summarized in three steps: developing a system topology with the maximum possible reliability, reducing the resultant system to a system with generic components, for each of which several alternatives exist including non-existence of the component, and a final step involving selecting a set of alternatives limiting the probability of system failure at a minimum total cost. Determining the set of alternatives for the components can be facilitated through the following elements.

1) The goal of risk based design for marine system and its goal is to enhance safety. advantage of such system in system design include:
2) Establishment of systematic method, tools to assess operational, extreme, accidental and catastrophic scenarios and integrating human elements into the design environment
3) Development of safety based technology for reliable operation and deign
4) Establishment of regulatory framework to facilitate first principle approach to facilitate first principle approaches to safety
5) Development of model that can demonstrate validation and practicability

6) Today, design shift towards knowledge intensive product, risk based design is believed to be key elements for enhancement of industrial competitiveness. The use of risk based design, operation and regulation open door to innovation and radical novel and inventive, and cost effective design solution. Risk based approach for ROV follow well established quantitative risk analysis used in offshore industries. The key to successful use of risk based design require advance tool to determine the risks involved and to quantify the effects of risk preventing/reducing measures as well as to develop (evaluation criteria to judge their cost effectiveness. Components of integrated risk includes:
7) Front End: Model potential causes, locations, sizes, and likelihoods of acid releases from System. Analysis of system capabilities: identify those releases that are mitigatable.
8) Successful mitigation: release less than 1,500 gallons
9) Consideration of diagnosis and response times
10) Back End: Model potential failure modes of each system design, and estimate failure likelihoods
11) Analysis of system reliabilities reliability block diagram analysis systematic identification of failure modes: human errors, equipment failures, support system failures
12) Analysis of consequences of unmitigatable or unmitigated releases:
13) Release size used as surrogate consequence measure

Risk can be calculated from:

$$R = \Sigma \text{ (Im x Amn x Cm)} + \quad \text{(Ji x Di)} \qquad (1)$$

Where:. R = Risk metric, . Im = Annual probability of mitigatable leak at location/size m, . Ji = Annual probability of unmitigatable leak at location/size I,. Amn = Probability of AIES failure via moden given leak m,. Cm/Di = Consequence severity of leak m.

ROV operating capabilities requirement that can be investigated is under risk based design are:

1) Standardized intervention ports for all subsea BOP stacks to ensure compatibility with any available ROV
2) Visible mechanical indicator or redundant telemetry channel for BOP rams to give positive indication of proper functioning (e.g., a position indicator).
3) ROV testing requirements, including subsea function testing with external hydraulic supply.
4) An ROV interface with dual valves below the lowest ram on the BOP stack to allow well-killing operations.
5) Electrical power requirement

General requirements - refer to SOLAS requirements. Chapter II-1 - outlines requirements for Ship construction sub-division and stability, machinery and electrical installations. The five part of this parts are: Part A –General, Part B -Sub-division and stability, Part C-Machinery installations, Part D -Electrical installations, Part machinery spaces.

IV. Benefits and Limitations of Using Risk and Reliability Models

Rampant system failure and problems related to reliability have brought the need to adopt a new philosophy based on top down risk and life cycle model to design, operate and maintain systems based on risk and reliability. Likewise, election of alternative ways to mitigate challenges of safety and environmental risk of system deserve holistic, reliability analysis approaches that provide the following benefits:

1) flexibility and redundancy for innovative, alternative improvised design and concept development
2) evaluation of risk reduction measure and transparency of decision making process
3) systematic tool to study complex problem
4) interaction between discipline
5) risk and impact valuation of system
6) facilitate proactive approach for system, safety, current design practice and management
7) facilitate holistic touching on contributing factor in system work
8) systematic rule making, limit acceptability and policy making development
9) analysis of transportation system

The dynamic distributive condition, long incumbent period and complexity of marine system with limited oversight makes the process of identification and addressing human as well as organizational error including checks and balances, redundancy, and training more complicated. Other inherits drawbacks associated with risk and reliability model are [5, 6]:

1) lack of historical data (frequency, probability, expert judgment)
2) linking system functionality with standards requirement during analysis (total safety level vs. individual risk level, calculation of current safety level)
3) risk indices and evaluation criteria (individual risk acceptance criteria and sustainability balance)
4) quantification of human error and uncertainty

The complexity associated with human and organization requires human reliability assessment and uncertainty analysis to be modeled independently.

V. Marine Pollution Risk Challenges

A group of experts on the scientific aspects of marine pollution comment on the condition of the marine environment in 1989, stated that most human product or waste ends their ways in the estuarine, seas and finally to the ocean. Chemical contamination and litter can be observed from the tropics to the poles and from beaches to abyssal depths. But the conditions in the marine environment vary widely. The open sea is still considerably clean in contrast to inland waters. However, time continue to see that the sea is being affected by man almost everywhere and encroachment on coastal areas continues worldwide, if unchecked. This trend will lead to global deterioration in the quality and productivity of the marine environment [5].

This shows the extent and various ways human activities and uses water resources affect the ecological and chemical status of waterways system. Occurrence of accident within the coastline is quite prohibitive due to unimaginable consequences and effects to coastal habitats. Recent environmental performance studies on transportation mode has revealed that transportation by water provides wide advantages in term of less, low Green House Gas (GHG) release, large capacity, congestion, development initiative etc. These advantages tells about high prospect for potential modal shift of transportation and future extensive use of inland water marine transportation where risk based system will be necessary to provide efficient, sustainable and reliability safe clean waterways as well as conservation of environment.

This equally shows that increase in human activities will have potential effects in coastal and marine environment, from population pressure, increasing demands for space, competition over resources, and poor economic performances that can reciprocally undermine the sustainable use of our oceans and coastal areas. Different forms of pollutants and activities that affect the quality of water, air and soil as well as coastal ecosystems are: Water: pollution release directly or washed downed through ground water; Air pollution, noise population, vibration; Soil: dredge disposal and contaminated sediments; Flood risk: biochemical reaction of pollution elements with water; Collision: operational; and Bio diversification: endangered and threatened species, habitat.

Main sources of marine pollution: i. Point form pollution: toxic contaminants, marine debris and dumping. ii. Nonpoint form pollution: sewage, alien species, and watershed Issues.

Main sources from ships are in form of: i. Operational: operational activities along the shipping routes discharging waters contaminated with chemicals (whether intentionally or unintentionally). ii. Accidental risk: Collision due to loss of propulsion or control.

Risk associated with environmental issue in the context of ship, design has impacts related to shipping trends, channel design criteria, ship and oil platform manoeuvrability and dynamic positioning and ship controllability.

VI. Modeling the Risk and Reliability Components of Complex and Dynamic System

The consequence of maritime accident comes with environmental problem. Marine system are dynamic system that have potential for high impact accidents which are predominately associated with equipment failure, external events, human error, economic, system complexity, environmental and reliability issues. This call for innovative methods, tools to assess operational issue, extreme accidental and catastrophic scenarios. Such method should be extensive use to integration assessment of human element, technology, policy, science and agencies to minimise damage to the environment. Risk based design entails the systematic risk analysis in the design process targeting risk prevention and reduction as a design objective. They should be integrated with design environment to facilitate and support sustainable approach to ship and waterways designs need (See Figure 1)

Figure 1: Risk modeling Components

Integrated risk based system design requires the availability of tools to predict the safety performance and system components as well as integration and hybridization of safety and environmental factors, lifecycle phases and methods. It important to develop refines, verify, validate through effective methods and tools. Such integrative and total risk tools required logical process with holistic linkage between data, individual risk, societal, organizational, system description, conventional laws, principle for system design and operation need to be incorporated in the risk process. Verification and employment of system based approach in risk analysis should be followed with creation of database and identification of novel technologies required for implementation. Unwanted event which remain the central front of risk fight is an occurrence that has associated undesirable outcome which range from trivial to catastrophic. Depending on conditions and solution based technique in risk and reliability work, the model should be designed to protect investment, properties, citizens, natural resources the institution which has to function in sustainable manner within acceptable risk.

The risk reliability modeling process begins with definition of risk which stands for the measure of the frequency and severity of consequence of an unwanted event. Frequency at which a potential undesirable event occurs is expressed as events per unit time, often per year. Upon establishing understanding of whole system from baseline data that include elements of channel and vessel dimensioning as shown in figure 3, the frequency can be determined from historical data. However, it is quite inherent that event that does not happen often attract severe consequence and lack data, such event is better analysed through probabilistic and stochastic model hybrid with first principle and whatever data is available [9]. Incidents are unwanted events that may or may not result to accidents if necessary measure is taken according to magnitude of event and required speed of response. While accidents are unwanted events that have either immediate or delayed consequences. Immediate consequences variables include injuries, loss of life, property damage and persons in peril. Point form consequences variables include further loss of life, environmental damage, and financial costs.

Risk (R) = Probability (P) X Consequence (C) (2)

The earlier stage of the risk and reliability process involves finding cause of risk, level of impact, destination and putting a barrier by all means in the pathway of source, cause and victim. Risk and reliability process targets the following:

1) Risk analysis and reduction process: This involves analytic work through selective deterministic and probabilistic method that assures reliability in the system. Reduction process will target initial risk reduction at design stage, risk reduction after design in operation and separate analysis for residual risk for uncertainty and human reliability. Risk in complex systems can have its roots in a number of factors ranging from performance, technology, human error as well as organizational cultures, all of which may support risk taking or fail to sufficiently encourage risk aversion.
2) Cause of risk and risk assessment: this involve system description, identifying the risk associated with the system, assessing them and organizing them according to degree of occurrence and impact in matrix form causes of risk can take many ways including the following:
    i. Root cause: Inadequate operator knowledge, skills or abilities, or the lack of a safety management system in an organization.
    ii. Immediate cause: Failure to apply basic knowledge, skills, or abilities, or an operator impaired by drugs or alcohol.
    iii. Situation causal factor**:** Number of participants time/planning, volatility environmental factors, congestion, time of day risk associated with system can be based on.
    iv. Organization causal factor**:** Organization type, regulatory environment, organizational age management type/changes, system redundancy, system incident/accident history, individual, team training and safety management system.

To deal with difficulties of risk migration marine system (complex and dynamic by nature), reliability assessment models can be used to capture the system complex issues as well as patterns of risk migration. Historical analyses of system performance is important to establish performance benchmarks in the system and to identify patterns of triggering events which may require long periods of time to develop and detect. Likewise, assessments of the role of human / organizational error and their impact on levels of risk in the system are critical in distributed, large-scale systems. This however imposes associated physical oversight linked to uncertainty during system design. Effective risk assessments required three elements: 1). Framework, 2). Model, 3. Process:

A. Risk Framework

Risk framework provides system description, risk identification, criticality, ranking, impact, possible mitigation and high level objective to provide system with what will make it reliable. The framework development involves risk identification which requires developing a structure for understanding the manner in which accidents, their initiating events and their consequences occur. This includes assessment of representative system and all linkages that are associated to the system functionality and regulatory impact.

B. Model

The challenges of risk and reliability method for complex dynamic systems like ship motion at sea require reliable risk models. Risk mitigation measures can be tested and the tradeoff between different measures or combinations of measures can be evaluated. Changes in the levels of risk in the system can be assessed under different scenarios and incorporating "what if" analyses in different risk mitigation measures. Performance trend analysis, reassessment of machinery, equipment, and personnel can be helpful in assessing the utility of different risk reduction measures. Figure 2 and 3 shows the risk components, system functionality and regulatory requirement for reliability model that can be followed for each risk scenario.

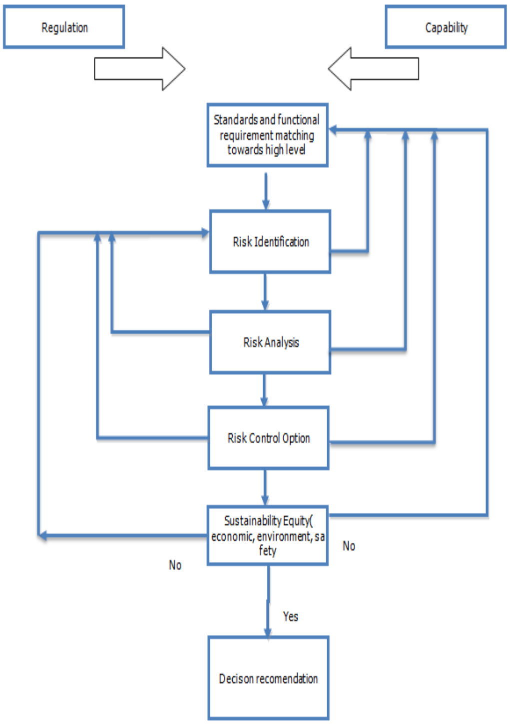

Figure 2: Risk model

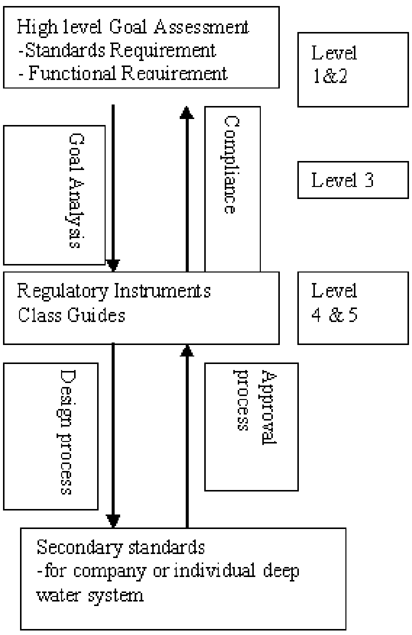

Figure 3: Goal based assessment

C. Process

The process should be developed to provide effective and sound risk analysis where accuracy, balance information that meets high scientific standards of measurement can be used as input. This requires getting the science right and getting the right science by targeting interests of stakeholders including port, waterway community, public officials, regulators and scientists. Transparency, community participation, additional input to the risk process, checks the plausibility of assumptions could help ask the right questions of the science.

Total integrated risk can be represented by:

$$Rt = fs\ (Rc,\ Rw, Re,\ Rs) \tag{3}$$

Where: Re (environment) = fe (sensitivity, advert weather…), Rs (ship) = fs (structural and system reliability, ship layout and cargo arrangement…), Rc (crew) = fc (qualification, fatigue, etc)

Holistic and integrated risk based method combined various techniques in a process as depicted in Figure 6, this can be applied for each level of risk for system in question. Each level is complimented by applying causal analysis (system linkage), expert analysis (expert rating) and organizational analysis (Community participation).

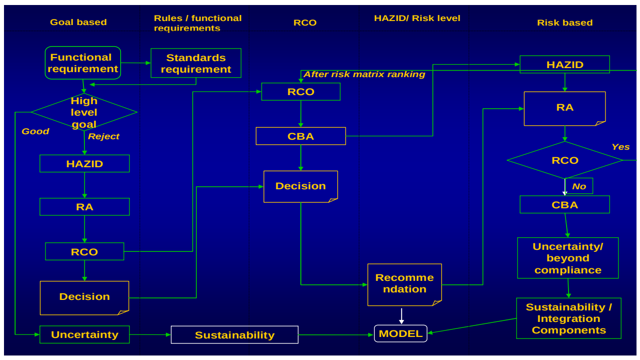

Figure 4: Holistic Risk analysis Process Map

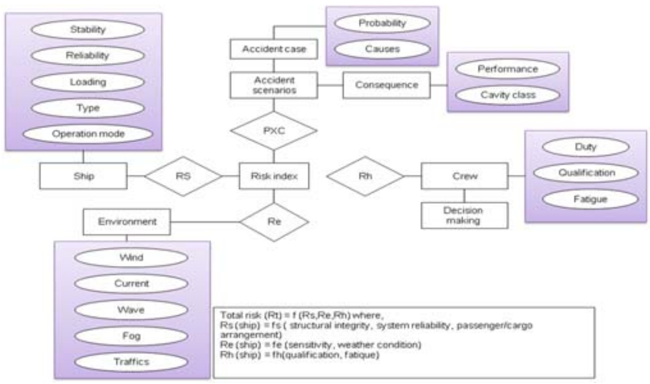

Figure 5: Holistic risk analysis process

Table 1 shows models that have been used in the design system based on risks. IMO and Sirkar et al (1997) methods lack assessment of the likelihood of the event. Other models lack employment of stochastic method whose result may cover uncertainties associated with dynamic and complex components of channel, ship failure and causal factors like navigational equipment, better training and traffic control . Therefore, combination of stochastic, statistical, reliability and probabilistic together with hybrid employment of goal based, formal safety assessment methods and fuzzy multi criteria network method that use historical data of waterways, vessel environmental and traffic data could yield efficient, sustainable and reliable design product for complex and dynamic systems. The general hypothesis behind assessing physical risk model of ship in waterways is that the probability of an accident on a particular transit depends on a set of risk variables which required to be analyzed for necessary conclusion of prospective reliable design [10].

TABLE 1: RISK MODELS

Process	Suitable techniques
HAZID	HAZOP, What if analysis, FMEA, FMECA
Risk analysis	FTA, ETA
Risk evaluation	Influence diagram, decision analysis
Risk control option	Regulatory, economic, environmental and function elements matching and iteration
Cost benefit analysis	ICAF, Net Benefit
Human reliability	Simulation/ Probabilistic
Uncertainty	Simulation/probabilistic
Risk Monitoring	Simulation/ probabilistic

Risk and reliability modeling involves hazard identification, risk screening, broadly focused, narrowly focused and detailed Analysis**,** Table 2 shows iterative method that can be incorporated for various needs and stages of the process.

VII. ACCIDENT ANALYSIS

Accident and incident need to be prevented as the consequence of is a result of compromise to safety leading to unforgettable losses and environmental catastrophic. Past engineering work has involved dealing with accident issues in reactive manner. System failure and unbearable environmental problems call for new proactive ways that account for equity requirement for human, technology and environment interaction in the system. The accidental categories and potential failure in waterways is shown in Figure 7.

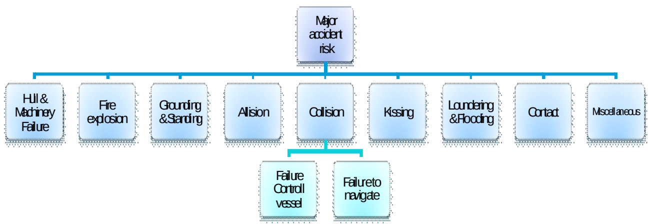

Figure 7: Accident scenario

The methodologies that may be used to identify safety critical systems, subsystem and elements include:

i. Major Accident Hazard; definition, examples, compliance with regulations such as SEVESOII (COMAH) and PFEER.
ii. Qualitative method for determination of the safety risk including:- Brainstorming session methodology and example- safety criticality criteria- Required supporting documents and evidences- Action tracking
iii. Quantitative method for frequency and consequence analysis.

Quantitative risk analysis (QRA) is widely use quantitative method for offshore industry, while formal safety assessment (FSA) is use in marine industry. QRA should be simplified for to be used for determination for safety criticality criteria, safety criticality test for failure on demand and time of test/repair, HSE toolkit application, combined Event tree, Fault tree Analysis**.** Standards safety critical elements identification could be analyzed through development of risk matrix, regulation scope and boundary compliance, performance standard and assessment, system capability , functionality, reliability, survivability assurance and verification analysis.The dynamic risk analysis process starts with system description, functionality, regulatory determination and this is followed with analysis of [3]:

1) Fact gathering for understanding of contribution factor
2) Fact analysis for check of consistency of accident history
3) Conclusion on causation and contributing factor

Countermeasures and recommendations for prevention of accident ` and studies of the system or project.

Major areas of concern of HSE analysis are:

1) Examination of relevant case of risk, hazard, Process Safety and reliability leading to HAZID
2) Identification of Safety Critical Elements,
3) Examination and comparison of performance standards
4) Examination of release and consequence model (Fire, Explosion and Toxic Release Consequence Modelling & Design)
5) Training on fundamental of the Risk Assessment & Case Study and Implementation of HSE Management System
6) Conduct of HAZOP Methodology and Simultaneous Operation
7) Risk Based Design acceptability criteria and & Integrity Assurance
8) Applications of Dynamic Simulation in Process Safety Design
9) Risk management, life cycle, traceable and auditable reference different phases of the project.

Risk analysis is conducted using brainstorming worksheets, action tracking and follow-up. HAZID, HAZOP involve Process safety Engineers, plant managers, safety supervisors, process engineers, safety Engineers and discipline engineers. Elements of QRA include: Failure Case definition, Consequence assessment, Frequency analysis, Risk calculation, ALARP demonstration, Identification of Safety Critical Systems, Traceability and audibility of Safety Critical Elements.

VIII. HAZARD OPERABILITY (HAZOP)

Hazard operability (HAZOP) is done to ensure that the systems are designed for safe operation with respect to personnel, environment and asset. In HAZOP all potential hazard and error, including operational issues related to the design is identified. A HAZOP analysis is detail HAZID, it mostly divided into section or nodes involve systemic thinking and assessment a systematic manner the hazards associated to the operation. The quality of the HAZOP depends on the participants. Good quality of HAZOP participants are [15]: Politeness and unterupting, To the point discussion- avoid endless discussion, Be active and positive, Be responsible and Allow HAZOP leader to lead

It involve How to apply the API 14C for those process hazard with potential of the Major Accident. Dynamic simulation for consequence assessment of the process deviation, failure on demand and spurious function of the safety system, alarm function and operator intervention is very important for HAZOP study. Identification of HAZOP is followed with application of combined Event tree and Fault tree analysis for determination of safety critical elements, training requirement for the operators and integrity and review of maintenance manuals.

HAZOP involved use of the following:

1) Guide word :i.e. No pitch, No blade
2) Description: I.e. No rotational energy transformed, object in water break the blade
3) Causes: i.e. operation control mechanism
4) Safety measurement to address implementation of propeller protection such grating, jet

The following are some of the guideword that can be used for Propulsion failure HAZOP includes: no pitch, no blade, no control bar, no crank.

HAZOP process is as followed:

Guide word/ brainstorming -> Deviation -> Consequence -> Safeguard ->Recommended action

Also important HAZOP is implementation of IEC61511 to assess the hazards associated to failure on demand and spurious trips. In HAZOP record the worksheets efficiently to cover all phases also play important role. Advance HAZOP can also e implemented through Simulation operations to identify, quantify, and evaluate the risks. SIMOP Methodology includes: Consequence Assessment, Frequency Analysis, Risk Calculation, Risk Analysis, and Safety Criticality Elements. HAZOP is not intended to solve everything in a meeting. Identified hazard is solved in the closing process of the finding from the study. Table 2 shows typical HAZOP report.Safety barrier management involves optimisation between the preventive and mitigation measures fundamental.

Safety barrier management helps in determination of the safety critical elements (SCE), performance standards for the design of safety Critical Elements and in integrity assurance. Safety level integrity (SIL) involves assessment and verification according to IEC61508 and IEC61511Qualitative SIL assessment uses the risk graphs and calibration tables during the brainstorming sessions where the required SIL is assigned to the safety systems. Integrity and insurance Involve iteration of assessment of identification the credible scenarios, consequence assessment, frequency analysis, risk calculation, risk evaluation and ranking. Dynamic simulation help to identify the process hazards, measure the extent and duration of the consequences and the effect and efficiency of the safety barriers. With dynamic simulation could be optimised with greater accuracy. This saves a significant effort, time and cost for the project. It involves application of: HAZOP & SIL assessment, Alarm Management, Fire & Explosion and Case study.

TABLE 2: TYPICAL HAZOP REPORT

Compression area	Fire	Hot work	3
Manfold area	Toxicity	Radioactive products	4
HP gas area	PPE		2
Separation area	Management of work permit (A)	If PTW is not followed correctly , the accident may happen	3
Compressor area	Fire & Explosion		3
Process area	Handling	Halding of proximity of process under pressure	4
Untility area	Fire fighting system	No availability of Fire Fighting system	2
Seperation	Fire & Explosion	Escape routes are obstructed	3
	PPE	Contractor not using PPE	2
	PPE		3
Tank area	Fire	No Fire & Gas detection	2
Compression area	Explosion	Escape routes are obstructed	3
Compression area	Fire	Hot work	3
Manfold area	Toxicity	Radioactive products	4

A. *Subsystem analysis - Fire and explosion*

Consequence modelling of Fire, Explosion and Toxic release, understanding of the fundamental and the science , governing scenarios; consequence analysis criteria. Gas dispersion & hazardous area classification, Fire zones (passive fire protection zones, the active fire protection zones, Blast Zones, blast protection zones restricted areas) Thermal & blast effect on equipment, people and environment is important to be incorporated in the risk process. Figure 8 shows a typical fire and explosion risk model.

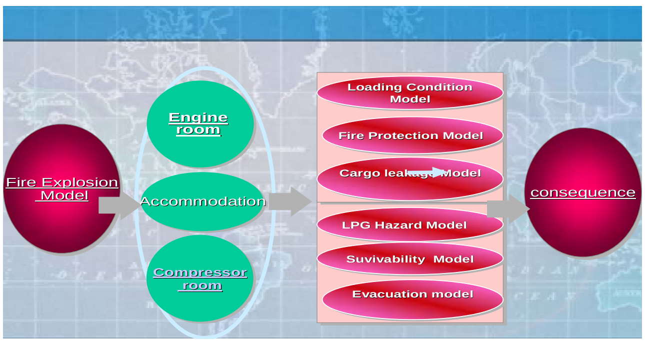

Figure 8: Typical fire and explosion risk model

IX. COLLISION SCENARIO

Collision is the structural impact between two ships or one ship and a floating or still objects that result could to damage. Collision is considered infrequent accident occurrence whose consequence in economical, environmental and social terms can be significant. Prevention of collision damages is likely to be more cost-effective than mitigation of its consequences. Probabilistic predictions can be enhanced by analyzing operator effects, drifting and loss of power or propulsion that take into account ship and waterway systems, people and environment into consideration. Other causative factor like the probability of disabled ship as function of ship type, the probability of a disabled ship drifting towards objects also need to be accounted for. The collision model scenario also involves data that characterize of hull areas and environmental information. Figure 9 show a typical collision consequence situation [6], [7].

Figure 9: Cause of collision (Langat River)

Outcome of analysis is followed by suitable Risk Control Options (RCO), where iteration of factual functionality and regulatory elements is checked with cost. The benefit realised from safety, environmental protection and effect of the probability of high level of uncertainty associated with human and organizational contributing factor to risk of collision are also important. The risk process functions to determine and deduce the idea for modest, efficient sustainable and reliable system requirement and arrangement [11], [14]. Collision carried the highest statistic in respect to ship accident and associated causality.

The consequences of accident are:

i. The loss of human life, impacts on the economy, safety and health, or the environment;
ii. The environmental impact, especially in the case where large tankers are involved. However, even minor spills from any kind of merchant ship can form a threat to the environment;
iii. Financial consequences to local communities close to the accident, the financial consequence to ship-owners, due to ship loss or penalties;
iv. Damage to coastal or off shore infrastructure, for example collision with bridges;

Accident events are unplanned, always possible, but effectively manageable and frequently preceded by related events that can be detected and corrected by having underlying root causes ranging from human errors, equipment failures, or external events. The result of frequency and consequence analysis is checked with risk acceptability index for industry of concerned. Table shown in Tables 3 and 4 show risk acceptability criteria for maritime industry. The analyzed influence diagram deduced from the comparison can be followed with cost control option using cost of averting fatality index or Imply Cost of Averting Fatality (ICAF) and As Low as Reasonable Possible (ALARP) principle [12].

TABLE 3: FREQUENCY RISK ACCEPTABILITY CRITERIA FOR MARITIME INDUSTRY.

Frequency classes	Quantification
Very unlikely	once per 1000 year or more likely
Remote	once per 100- 100 year
Occasional	once per 10- 100 year
Probable	once per 1- 10 years
Frequent	more often than once per year

TABLE 4: CONSEQUENCE RISK ACCEPTABILITY CRITERIA FOR MARITIME INDUSTRY

Quantification	Serenity	Occurrence	Detection	RPN
Current failure that can result to death failure, performance of mission	catastrophic	1	2	10
Failure leading to degradation beyond accountable limit and causing hazard	critical	3	4	7
Controllable failure leading to degradation beyond acceptable limit	major	4	6	5
Nuisance failure that do not degrade system overall performance beyond acceptable limit	minor	7	8	2

X. FAILURE MODES EFFECT ANALYSIS (FMEA)

A Failure Modes Effect Analysis (FMEA) is a powerful bottom up tool for total risk analysis. FMEA is probably the most commonly used for qualitative analysis and is also the least complex. FMEA has been employed in the following areas: The aerospace industry during the Apollo missions in the 1960s.The US Navy in 1974 developed a tool which discussed the proper use of the technique. Today, FMEA is universally used by many different industries. There are three main types of FMEA in use today: System FMEA: concept stage design system and sub-system analysis. Design FMEA: product design analysis before release to manufacturers. Process FMEA: manufacturing assembly process analysis.FMEA process is shown in Figure 10:

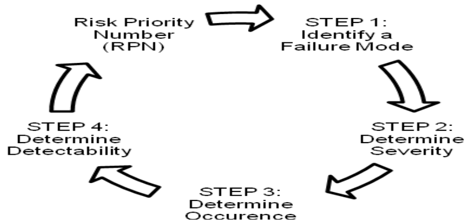

Figure 10: FMEA process

It is strongly recommended that Serenity, Occurrence and Detection (SOD) for weak control should be noted. SOD numbers is multiplied and the value is stored in RPN (risk priority number) column. This is the key number that will be used to identify where the team should focus first. If, for example, we had a severity of 10 (very severe), occurrence of 10 (happens all the time), and detection of 10 (cannot detect it) RPN is 1000. This indicates a serious situation that requires immediate attention. The consequence could further be broken down into effect for ship, human safety, oil spill, damage, ecology, emission and other environmetal impacts. Number 1-10 are assigned according to level of serenity. Risk priority number (RPN) for total serenity is determining as follows Table 5 show typical risk matrix arrangement:

$$RPN = S \times O \times D \tag{4}$$

ALARP Principal, Risk Acceptability Criteria And Risk Control Option

Risk acceptability criteria establishment is dynamic because of differences in environment, diversity in industries and choice of regulations requirement to limit the risk. Risk is never acceptable, but the activity implying the risk may be acceptable due to benefits of safety reduced, fatality, injury, individual risk, societal risk, environment and economy. The rationality may be debated, societal risk criteria are used by increasing number of regulators. Figure 11 shows ALARP diagram by IMO (Skjong et al., 2005).

TABLE 5: RISK MATRIX

			Consequence Criteria				
			1 Insignificant	2 Minor	3 Moderate	4 Major	5 Catastrophic
Likelihood	A -	The consequence is almost certain to occur in most circumstances	Medium (M)	High (H)	High (H)	Very High (VH)	Very High (VH)
	B -	The consequence is likely to occur frequently	Medium (M)	Medium (M)	High (H)	High (H)	Very High (VH)
	C -	Possible and likely for the consequence to occur at some time	Low (L)	Medium (M)	High (H)	High (H)	High (H)
	D -	The consequence is unlikely to occurbut could happen	Low (L)	Low (L)	Medium (M)	Medium (M)	High (H)
	E -	The consequence may occur but only in exceptional circumstances	Low (L)	Low (L)	Medium (M)	Medium (M)	High (H)

Figure 11 shows prescribed illustrative influence diagram by IMO. Based on the region where the graph falls, step for risk control option and sustainability balancing, cost benefit effectiveness towards recommendation for efficient, reliable, sustainable decision can be taken. The frequency (F) of accidents involving consequence (N) or more fatalities may be established in similar ways as individual or societal risk criteria. For risks in the unacceptable/ Intolerable risk region, the risks should be reduced at any cost. Risk matrix constructed from system and sub system level analysis can be deduced according to acceptability index and defined according to Table 10 and Figure 11 to deduced measure of As Low As Reasonably Practicable (ALARP). Within ALARP range, Cost Effectiveness Assessment (CEA) or Cost Benefit Analysis (CBA) shown in Figure 11 may be used to select reasonably practicable risk reduction measures.

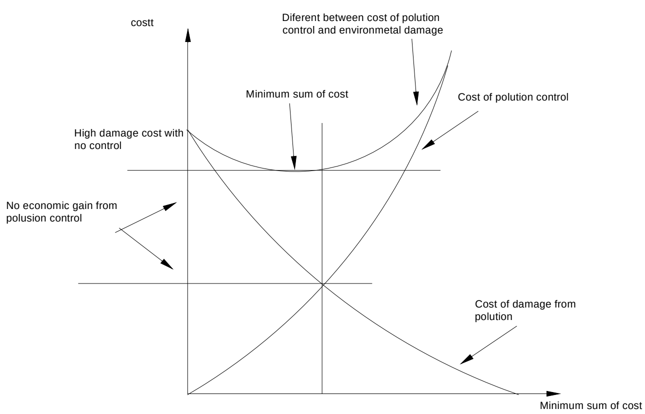

Figure 11: Risk cost benefit analysis

Risk Analysis Considerations

In addition to a sound process, robust risk framework and eventual deductive risk model, there are other considerations that should be factored into the design of an effective risk model. These items include the use of available data, the need to address human factors, areas of interest, stakeholder interest and approaches to treating uncertainty in risk analysis. Data required for risk work should involve information on traffic patterns, the environment (weather, sea conditions, and visibility), historical, current operational performance data, and human performance data. The models intentions are highly dependent on appropriately selected databases that accurately represent the local situation and the effectiveness of the models However, there is always issue of missing data or data limitations especially for complex system and their allow frequency, high consequence nature. Therefore creative procedures are required to develop compensation for data relationships. The model could use probabilistic, stochastic, simulation and expert judgments couple existing deterministic and historical method for a reliable system analysis of desired design [7].

When insufficient local data is available, world wide data from other areas may be referred to (e.g., Europe, south and North America), make assumptions about the similarity of operations in the concerned area or elsewhere. This is to ensure how behaviour in one aspect of operational (e.g., company management quality) parameter (e.g., loss of crew time) correlates with another area (e.g., operations safety). The data from other areas can be used as long as major parameter and environmental factors are compared and well matched. Care is required with the use of worldwide data as much of those data are influenced by locations or local environmental conditions Electronic access to worldwide casualty data such as the Paris MOU, U.K., and Marine Accident Investigation Board (MAIB) and IMO Port State detention databases makes possible access to worldwide casualty statistics. Diligence should also be observed about the large number of small scale, localized incidents that occur that are not tracked by marine safety authorities, e.g small craft (not always registered or being able to be detected by VTS, AIS) accidents in waterways. American Bureau of shipping (ABS) has begun an effort to identify precursors or leading indicators of safety in marine transportation.

Human factor modeling should be considered for distributive, large scale systems with limited physical oversight. Assessing the role of human and organizational performance on levels of risk in the system is important, such error is often cited as a primary contributor to accident, which end up leaving system with many more unknown. Expert judgments and visual reality simulation can be used to fill such uncertainty gaps and others like weather data. Even when attempts are made to minimize errors from expert judgments, the data are inherently subject to distortion and bias. With an extensive list of required data, there are limits that available data can place on the accuracy, completeness and uncertainty in the risk assessment results. Expert judgments give prediction about the likelihood that failures that would occur in specific situations can be used to quantify human reliability input in risk process.

Uncertainty is always part of system behaviour. Two common uncertainties are: aleatory uncertainty (the randomness of the system itself) and epistemic uncertainty (the lack of knowledge about the system). Aleatory uncertainty is represented by probability models while epistemic uncertainty is represented by lack of knowledge concerning the parameters of the model. Aleatory uncertainty is critical, it can be addressed through probabilistic risk analysis while epistemic uncertainty is critical to allow meaningful decision-making. Simulation offers one best option to cover extreme case uncertainty beside probability. Evaluation and comparison of baseline scenario to a set of scenarios of interest (tug escort) and operational circumstance including timelines and roles. Response Scenarios can also be analyzed for things that cannot be imagined or model to be accounted for in the simulator (especially real time). A flexible critical path and slack analysis can be performed as input to the system simulation and uncertainty analysis. Human reliability is best modeled separately for a good result [4].

Risk and reliability can be achieved by employing probability stochastic and expert rating in the risk process. A safety culture questionnaire which assesses organizational and vessel safety culture and climate can be administered to provide quantitative and qualitative input to the safety culture and environmental perception analysis for sustainable system design.

XI. Conclusion

Following need for maritime activities to operate in much harsh condition, institutions are adopting system based approach that account for total risk associated with system lifecycle to protect the environment and prevent accident. Those that cannot be prevented and protected need or must be controlled under risk and reliability based design / operability platform. Employment of risk method to address each contributing factor to accident is very important. Qualitative risk in system description and hazard identification can best be tackled through HAZOP. The outcome of HAZOP can be processed in quantitative analysis which may include probabilistic and stochastic dynamic simulation process for system level analysis, while fault tree and event tree quantitative analysis can be utilized to determine risk index of the subsystem factors. Interpretation of risk index into ALARP influence diagram can provide decision support information necessary for cost control option towards sustainable, reliable, efficient technology choice for system design and operation. The cumulative results from qualitative analysis can be made more reliable through iterative quantitative, scientific stochastic and reliability analysis. Risk methods provide valuable and effective decision support tool for application of automated system engineering analysis that facilitate inclusion of reliability, environmental protection and safety as part of the iterative design processes for new and innovative marine system designs, operability and deployment of deep sea operability system. Intelligently adoption of HAZOP and other risk processes eventually can results to safer, efficient, more reliable and sustainable system.

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