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Safety and Environmental Risk and Reliability Modeling Process for Sustainable Inland Water Transportation System

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The vast resources of the world's oceans need to be fully utilized to benefit human activities in a sustainable manner. The maritime industry has made use of the ocean in a very responsible way, but inland water resources have been much more underutilized and under-maintained, especially for transportation. In an age so dire to find ways to mitigate the challenge of climate change and its associated impacts, recent research has indicated that inland water transportation represents the cleanest mode of transportation. This indicates the potential for an increase in usage of inland waterways for transportation. The use of inland water transportation is forecast to rise because of the potential for short sea shipping, expanding deep-sea operations, and alternative mitigation options for climate change. Coastal water transportation is associated with low probability, high consequence accidents, which makes reliability requirements for the design and operation for safety and environmental protection very necessary. Collision represents the largest percentage of accident risk scenarios among water transportation risk factors. This paper discusses recent work in risk and reliability-based design, and safe and efficient vessel operation in coastal waters. This includes systems based approach that covers proactive risk as well as holistic, multiple-criteria assessment of waterways variables required to develop mitigation options and decision support for preventive, protective and control measures for various collision accident scenarios within inland waterways.

Keywords: Inland transportation, accidents, risk assessment, vessel safety, collisions, climate change, marine pollution, navigation

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1.0 INTRODUCTION

Marine transportation services provide substantial support to various human activities its importance has long been recognized. IMO cross boundary activities in maritime regulation contain lessons learned that could be a model for the quest for today's environmental global regulatory bodies to meet current environmental challenges and advancement of human civilization (SOLAS, 2004; Cahill R.A., 1983; Cooke, R.M. 1997). Most IMO regulatory works are not mandatory for coastal transportation. Except implementation issues that are directed through flag states and port state control. The clear cut advantage of inland water transportation system (IWTS) 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 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 sustainable, efficient and reliable coastal transportation systems. This include consideration for holistic characteristics that of environmental aspects of navigation channel, vessels and other water resources issues since a sustainable inland water system cannot stand alone. Waterway accidents fall under the scenarios of collision, fire and explosion, flooding, and grounding (Bottelberghs P.H., 1995; Murphy, D.M. & M.E. Paté-Cornell, 1996). Collision is caused by (see figure 1):

i) loss of propulsion.
ii) loss of navigation system.
iii) other accident from the ship or waterways.

This paper discusses risk and reliability model for the assessment and analysis of collision accident scenarios leading to design for the prevention, control of collisions and protection of the environment. The paper also discuss elements of the process that address requirement to optimize design, existing practice, and facilitate decision support for policy accommodation for evolving coastal transportation regimes.

2.0 RISK AND RELIABILITY MODELLING REQUIREMENT

In order to build reliable inland water transportation system, it is important to understand the need analysis through examination of the components of system functionality capability and standards requirement. These include major requirements and classification of coastal water transportation system. Also important is functionality capability like channel, vessel, terminal, and other support systems. 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 de-

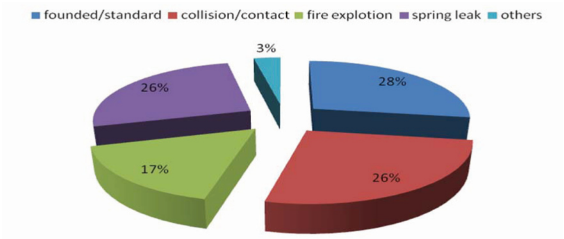


FIGURE 1
Waterways risk by accident categories [11].

velopment 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 (Report of marine accident, 2009). Weighing of deductive balancing work requirement for reliable and safe inland water transportation 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 practices 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 should be addressed.

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 States Coast Guard (USCG) rule making have issued guidelines and procedures for risk based decision making, analysis and management under formal safety assessment (Report of marine accident, 2009; Cooke, R.M. 1997; Det Norske Veritas, 2004). 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 consider the broader impacts of events, conditions, scenarios on geographical, temporal impacts, risks of conditions is important 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.

3.0 BENEFITS AND LIMITATIONS OF USING RISK AND RELIABILITY MODELS

Rampant system failure and problems related to system failure 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:

i. flexibility and redundancy for innovative, alternative improvised design and concept development
ii. evaluation of risk reduction measure and transparency of decision making process
iii. systematic tool to study complex problem
iv. interaction between discipline
v. risk and impact valuation of system

vi. facilitate proactive approach for system, safety, current design practice and management
vii. facilitate holistic touching on contributing factor in system work
viii. systematic rule making, limit acceptability and policy making development
ix. analysis of transportation system

The dynamic distributive condition, long incumbent period and complexity of marine system comes with limited oversight that make the process of identification and addressing human as well as organizational error difficult. This includes checks and balances, redundancy, and training more complicated. Inherit drawbacks associated with risk and reliability model are (SOLAS, 2006; SOLAS, 2006):

i. lacks of historical data (frequency, probability, expert judgment)
ii. linking system functionality with standards requirement during analysis (total safety level vs. individual risk level, calculation of current safety level)
iii. risk indices and evaluation criteria (individual risk acceptance criteria and sustainability balance)
iv. quantification of human error and uncertainty

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

4.0 MARINE POLLUTION RISK

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 (Murphy, D.M. & M.E. Paté-Cornell, 1996).

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 ocean and coastal areas. Different forms of pollutants and activities that affect the quality of water, air and soil as well as coastal ecosystems are:

i. Water: pollution release directly or washed down through ground water;
ii. Air pollution: noise population, vibration;
iii. Soil: dredge disposal and contaminated sediments.
iv. Flood risk: biochemical reaction of pollution elements with water;
v. Collision: operational;
vi. Bio diversification: endangered and threatened species, and 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 manoeuvrability and ship controllability.

5.0 MODELLING THE RISK AND RELIABILITY COMPONENTS OF COMPLEX AND DYNAMIC SYSTEM

The consequence of maritime accident comes with environmental problem. Marine systems 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 design need. Thus, enabling appropriate trade offs on advance decision making that consider size, speed, novelty, type and technology leading to optimal design solutions (Det Norske Veritas, 2004) (see figure 2).

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 is important to develop, refine, verify, validate through effective methods and tools. Such integrative and

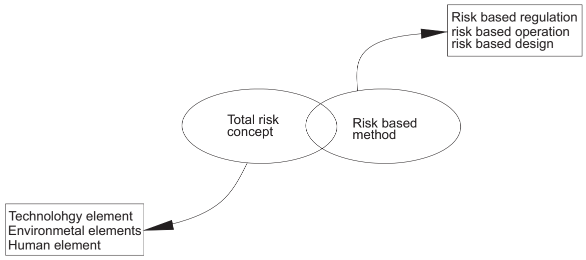


FIGURE 2
Risk modelling process.

total risk tools require 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 and the institution which has to function in sustainable manner within acceptable risk.

The risk and 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 shown in figure 3, the frequency can be determined from historical data. However, it is quite inherent that event that does not happen often attracts severe consequence and lack data. Such event is better analysed through probabilistic and stochastic model hybrid with first principle and use whatever data is available (Kite-Powell, H.L., D. Jin, N. M. Patrikalis, J. Jebsen, V. Papakonstantinou, 1996). 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 dam-

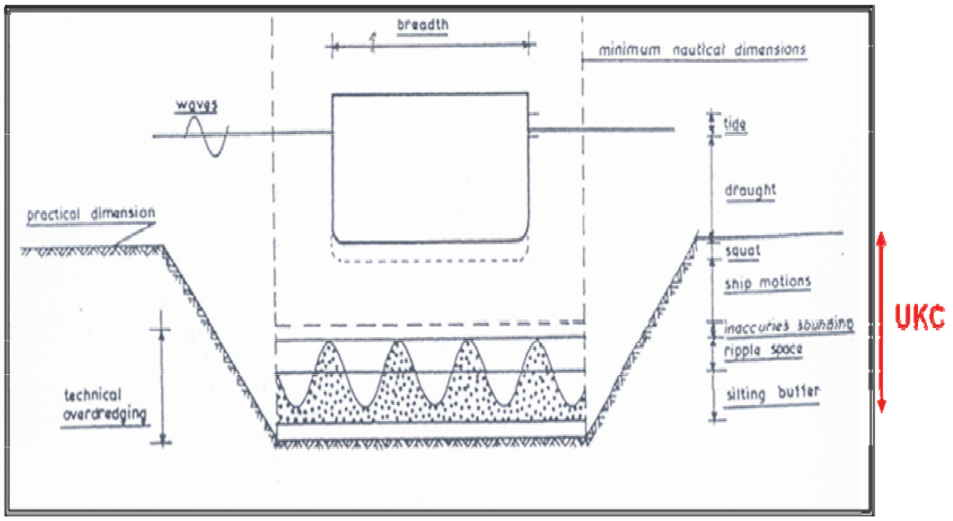


FIGURE 3
Channel and vessel dimension.

age, and financial costs. System risk can be estimated through equation 1.

$$\text{Risk } (R) = \text{Probability } (P) \text{ X Consequence } (C) \tag{1}$$

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:

i. 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.
ii. 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:

    a. Root cause: Inadequate operator knowledge, skills or abilities, or the lack of a safety management system in an organization.
    b. Immediate cause: Failure to apply basic knowledge, skills, or abilities, or an operator impaired by drugs or alcohol.
    c. Situation causal factor: Number of participants time/planning, volatility environmental factors, congestion, time of day risk associated with system can be based on.
    d. 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 (Emi H., et al., 1997). 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:

i. Framework
ii. Models
iii. Process

5.1 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.

5.2 Models

The challenges of risk and reliability method for complex and dynamic systems like ship motion at sea require reliable risk models. Risk mitigation measures can be tested and the trade off 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. Figures 4 and 5 show the risk components, system functionality and regulatory requirement for reliability model that can be followed for each risk scenario.

5.3 Processes

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 is additional input to the risk

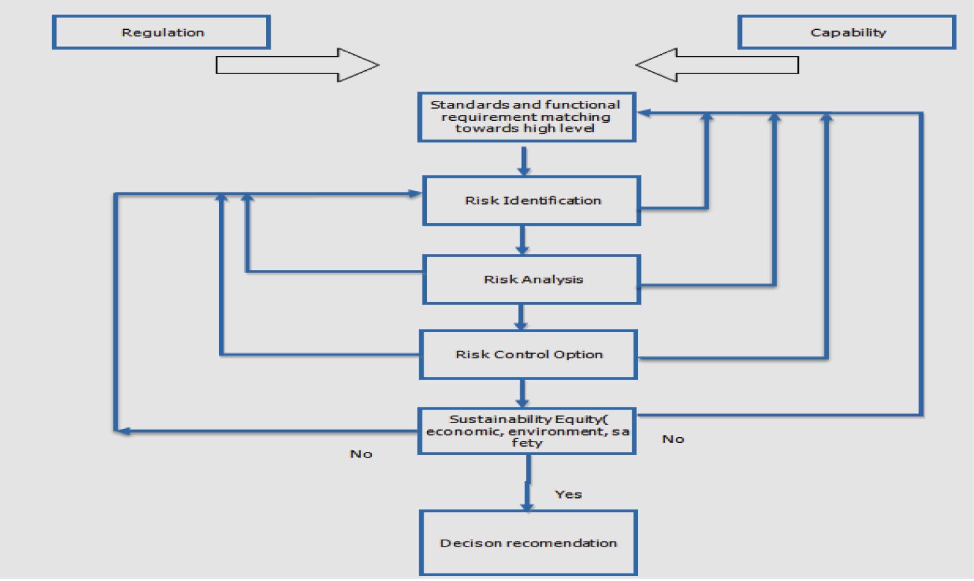


FIGURE 4
Risk model.

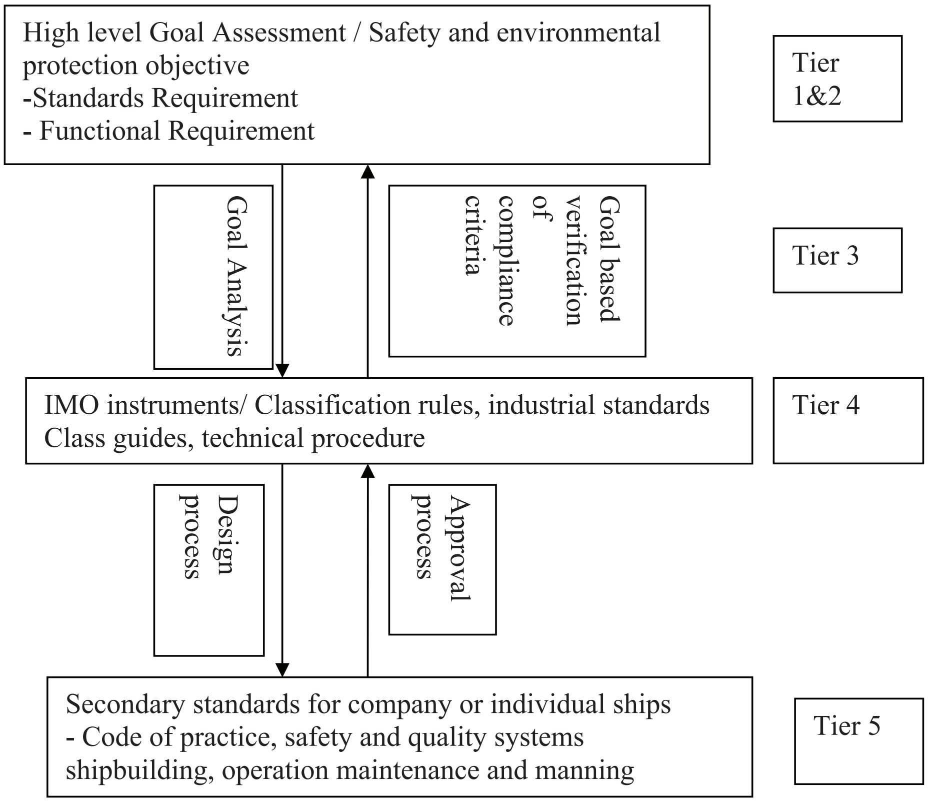


FIGURE 5
High level goal based assessment.

process; checks the plausibility of assumptions could help ask the right questions of the science. Figure 6 and 7 show the risk process diagram. (See appendix 1 for process log) Total integrated risk can be represented by:

$$Rt = f\,(Re, Rs, Rh) \tag{2}$$

Where: Re (environment) = f (sensitivity, advert weather…), Rs (ship) = f (structural and system reliability, ship layout and cargo arrangement…), Rh (crew) = f (qualification, fatigue, etc.)

Holistic and integrated risk based method combined various techniques in a process as depicted in Figure 8, 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).

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 (Guedes Soares, C., A.P. Teixeira, 2001; Emi, H. et al., 1997). Therefore, combination of stochastic, statistical, reliability and probabilistic together with hybrid employment of goal based, formal

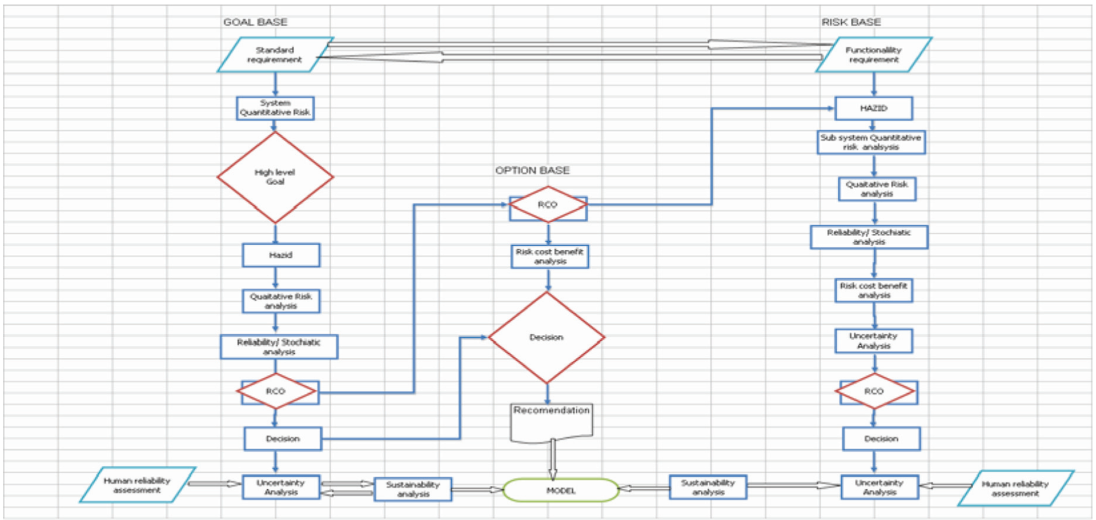


FIGURE 6
Holistic Risk analysis Process.

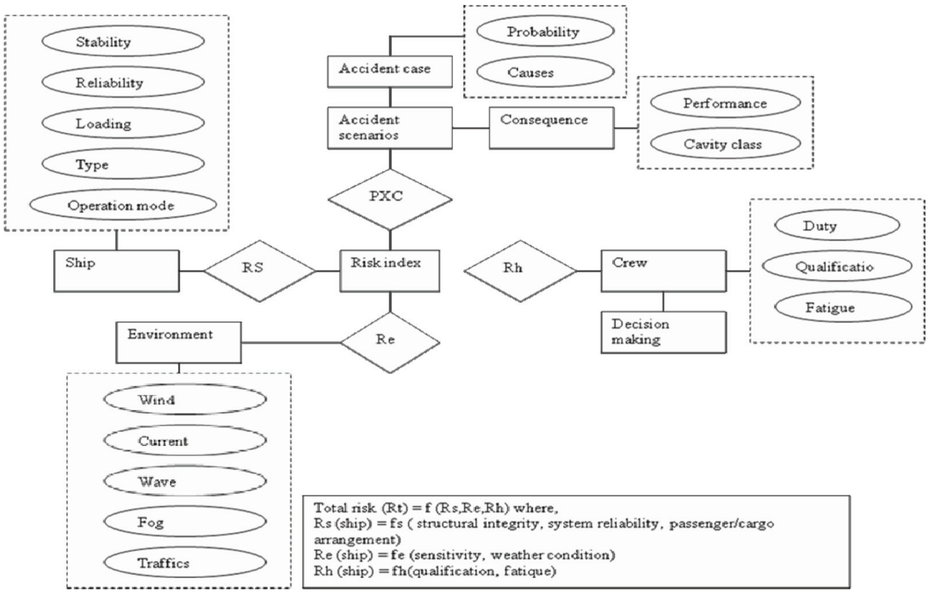


FIGURE 7
Holistic Risk analysis Process.

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

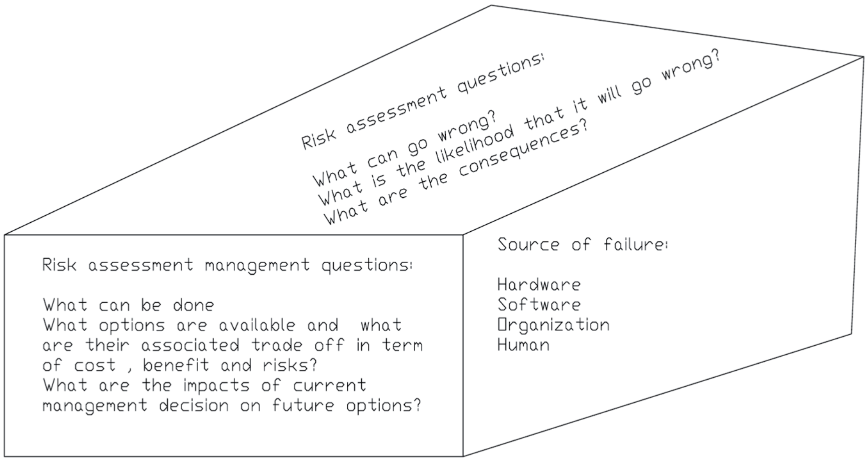


FIGURE 8
Total risk concept.

TABLE 1
Previous risk work.

Model	*Application*	*Drawback*
Brown et al (1996)	Environmental performance of tankers	
(Sirkar et al (1997))	Consequences of collisions and groundings	Difficulties on quantifying consequence metrics
Brown and Amrozowicz	Hybrid use of risk assessment, probabilistic simulation and oil spill consequence assessment model	Oil spill assessment limited to use of fault tre
Sirkar et al (1997)	Monte Carlo technique to estimate damage + spill cost analysis for environmental damage	Lack of cost data
IMO (IMO 13F 1995)	Pollution prevention index from probability distributions damage and oil spill.	Lack (Sirkar et al (1997)). rational
Research Council Committee (1999)	Alternative rational approach to measuring impact of oil spills	Lack employment of stochastic probabilistic methods
Prince William Sound, Alaska, (PWS (1996))	The most complete risk assessment	Lack of logical risk assessment framework (NRC (1998))
(Volpe National Transportation Centre (1997)).	Accident probabilities using statistics and expert opinion.	Lack employment of stochastic methods
Puget Sound Area (USCG (1999)).	Simulation or on expert opinion for cost benefit analysis	Clean up cost and environmental damage omission

accident on a particular transit depends on a set of risk variables which required to be analyzed for necessary conclusion of prospective reliable design.

Risk and reliability modeling involves hazard identification, risk screening, broadly focused, narrowly focused and detailed Analysis, Table 2 shows iterative method that can

TABLE 2
Process table.

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

be incorporated for various needs and stages of the process.

6.0 ACCIDENT ANALYSIS

Accident and incident need to be prevented as the consequence could result to 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 figures 9. Figure collision contributory factors modeled from RELEX software.

The whole process starts with system description, functionality, regulatory determination and this is followed with analysis of:

i. Fact gathering for understanding of contribution factor
ii. Fact analysis for check of consistency of accident history
iii. Conclusion on causation and contributing factor
iv. Countermeasures and recommendations for prevention of accident

The process is followed by probability and stochastic calculation analysis of cause and frequency model where value of each node extracted from data according to operational situation are used in system modeling. The process is then followed by severity calculation analysis of consequence model where the probability for each branch and the value of end state (severity) is fetched from modelled database.

6.1 Collision Scenario

Collision is the structural impact between two ships or one ship and a floating or still objects that could result to damage. Collision is considered infrequent accident occurrence whose consequence in economical, environmental and social terms can be significant.

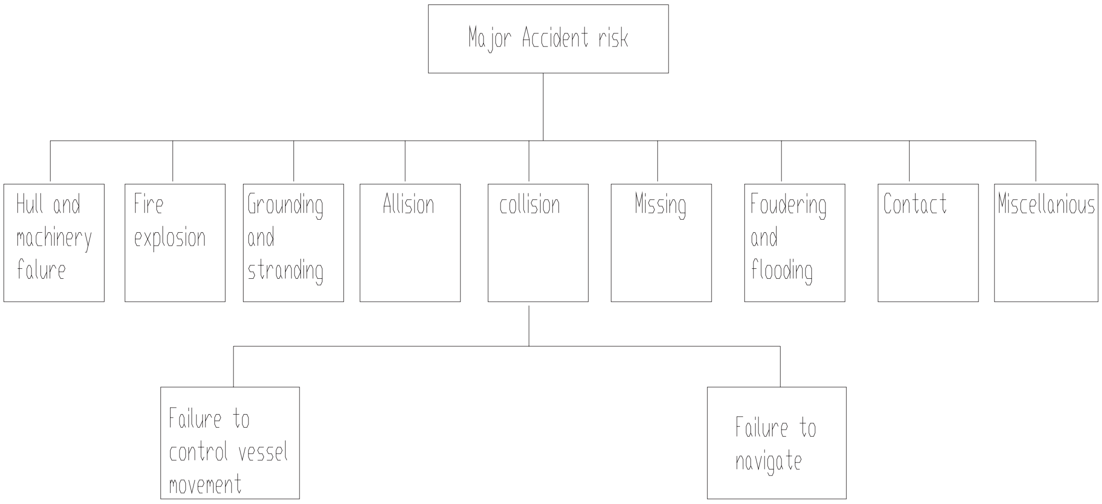


FIGURE 9
Accident scenario.

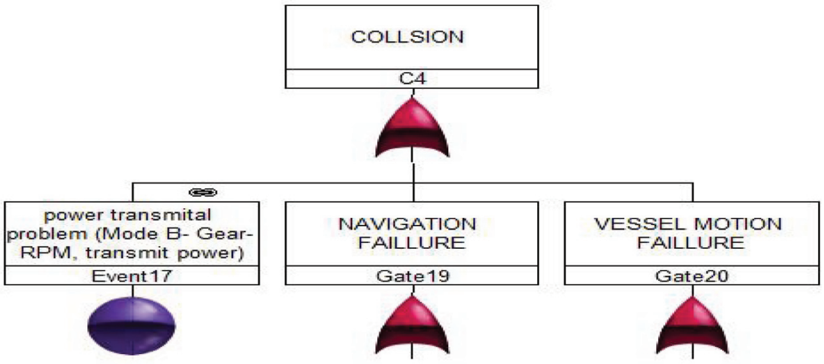


FIGURE 10
Collision contributing factors modelled from RELEX software.

Prevention of collision damages is likely to be more cost-effective than mitigation of its consequences. Probabilistic predictions can be enhanced by analysing operator effects, drifting and loss of power or propulsor that take into account ship and waterway systems, people and environment into consideration. Other causative factors 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 characteristic of hull areas and environmental information; major contributing factors to collision are shown in Figure 11.

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

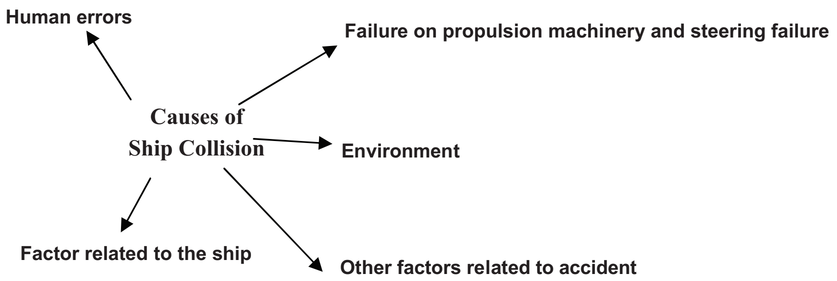


FIGURE 11
Cause of collision.

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 (Parry, G., 1996; Pate Cornell, M.E., 1996). Collision carried the highest statistic in respect to ship accident and associated causality. The consequences of collision 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.

Collision 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. Tables 3 and 4 show risk acceptability criteria for maritime industry. The analysed 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.

6.2 Failure Modes Effect Analysis (FMEA)

A Failure Modes Effect Analysis (FMEA) is a powerful bottom up tool for total risk

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

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:

i. The aerospace industry during the Apollo missions in the 1960s.
ii. 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:

i. System FMEA: concept stage design system and sub-system analysis.
ii. Design FMEA: product design analysis before release to manufacturers.
iii. Process FMEA: manufacturing assembly process analysis.

Analyzing FMEA involves:

i. Listing key process steps in firm column for the highest ranked items risk matrix.
ii. Listing the potential failure mode for each process step: how the process input could go wrong.
iii. Listing the effects of the failure mode: what does the failure mode mean to stakeholders.
iv. Rating severity of the effect : 1 being not severe at all and 10 being extremely severe.
v. Identifying the causes of the failure mode effect and rank the effects in the occurrence column: the scoring denotes how likely this cause will occur. Score of 1 means it is highly unlikely to ever occur and 10 means we expect it to happen all the time.
vi. Identifying the controls in place to detect the issue and rank its effectiveness in the detection column: 1 would mean there are excellent controls and 10 would mean there are no controls or extremely weak controls.

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, there is case with 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:

$$RPN = S \text{ X } O \text{ X } D \tag{3}$$

6.3 ALARP principal, risk acceptability criteria and risk control option

Consequence thresholds priority of value choice is awarded. The highest Consequence tripped in order of priority give the overall consequence. **Catastrophic:** Descriptors of catastrophic consequences for 1. People; 2. Infrastructure; 3. Values. **Major:** Descriptors of major consequences for 1. People; 2. Infrastructure; 3. Values. **Moderate:** Descriptors of moderate consequences for 1. People; 2. Infrastructure; 3. Values. **Minor:** Descriptors of minor consequences for 1. People; 2. Infrastructure; 3. Values. **Insignificant:** Descriptors of insignificant consequences for 1. People; 2. Infrastructure; and 3. Values.

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. Perception regarding acceptability is described by Green et al (1998). The rationality may be debated, societal risk criteria are used by increasing number of regulators.

Figure 12 shows prescribed illustrative influence diagram by IMO. Based on 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 defined according to table 5 and figure 12 to deduced measure of ALARP. Within ALARP range, Cost Effectiveness Assessment (CEA) or Cost Benefit Analysis (CBA) shown in Figure 13 may be used to select reasonably practicable risk reduction measures.

7.0 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

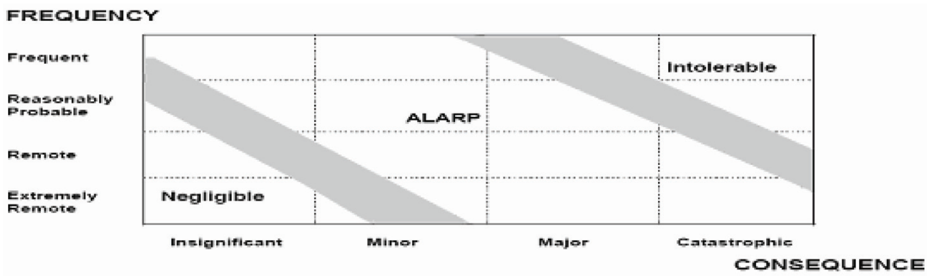
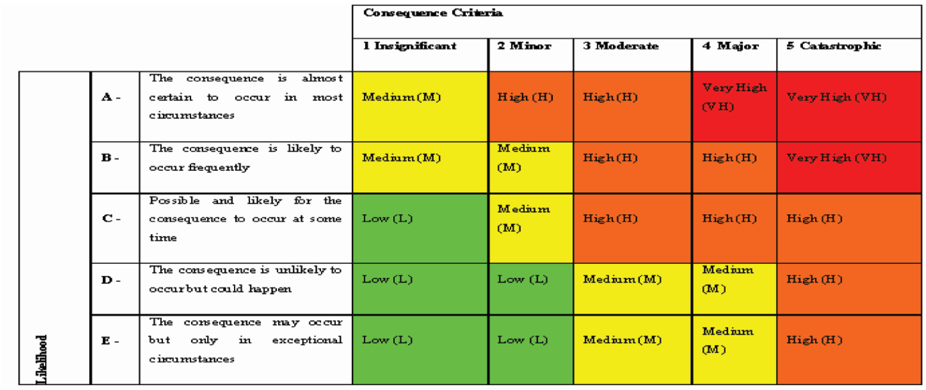


FIGURE 12
Influence diagram, ALARP = As Low As Reasonably Practicable: Risk level boundaries (Negligible/ALARP/Intolerable).

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)

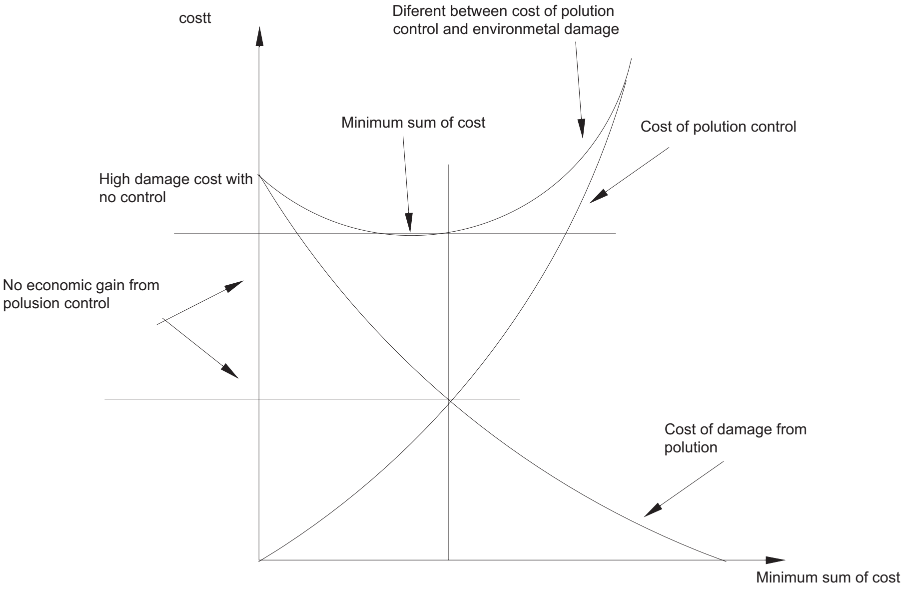


FIGURE 13
Risk cost benefit and sustainability analysis curve.

limitations especially for complex system and their low 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 (M. Kok, H.L. Stipdonk, W.A. de Vries, 1995; Stiehl, G.L., 1977).

When insufficient local data is available, world wide data from other areas may be referred to (e.g., Europe, south and North America). However, ones need to 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 parameters 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 (Skjong, R., 2002). Electronic access to worldwide casualty data such as the Paris MOU, U.K., 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 Factors modelling 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 (Pate Cornell, M.E., 1996). 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 of the best options to cover extreme case uncertainty besides probability. Evaluation and comparison of baseline scenario to a set of scenarios of interest (tug escort) and operational circumstance including timelines and roles can also be incorporated. Response Scenarios can also be analysed for things that can not be imagined or modeled 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 (Cahill (1983) and Emi et al., (1997)). A safety culture questionnaire which assesses organizational, 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.

7.1 Between Reliability and Validation

Further reliability work and validation of the risk analysis could be activated through the following:

i. Accident means, variance and standard deviation from normal distribution

$$\text{For 10 years} => \text{Mean } (\mu) = 10 \times Fc \qquad (4)$$

$$\text{Variance } (\sigma) = 10 \times Fc \times (1 - Fc),$$
$$\text{Standard deviation} = \sqrt{\sigma},\ Z = (X - \mu)/\sigma \qquad (5)$$

ii. Year for system to fail from binomial, mean time to failure and poison distribution. Poison distribution probability at N trial is represented by:

$$F_r\left(N/\gamma,T\right) = e^{\gamma,T}\left(\ \right)\gamma,\left(\gamma \cdot T\right)^N N! \qquad (6)$$

where $y = Fc$, T = time to fail

iii. Binomial distribution – for event that occurs with constant probability P on each trail, the likelihood of observing k event in N trail is binomial distribution.

$$L(K/N,P) = \begin{pmatrix} N \\ P \end{pmatrix} P^K \left(1-P\right)^{N,K} \qquad (7)$$

Average number of occurrence is NP

iv. Comparing the model behaviour application to other rivers of relative profile and vessel particular or comparison of improvement plan implemented like traffic separation scheme (TSS).
v. Triangulating analysis of sum of probability of failure from subsystem level failure analysis.
vi. Plotting of lognormal, probability density cumulative and density function.

8.0 CONCLUSION

Following irreparable and economic loses from traditional reactive action against accident and incessant system failure, institutions are evolving with hybrid proactive top down and bottom up 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.

Development of novel method to address each contributing factor to accident is very important. The potential for inland water is great and there is a need to implement IMO rules model to mitigate accident risk. Collision risk is much common and propulsion failure, loss of navigation control and human error are the sub system contributing factors. Preceding total risk qualitative system description and hazard identification, probabilistic and stochastic process quantitative analysis can be performed 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. These 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. Intelligently adoption of those processes eventually can result to safer, efficient, more reliable and sustainable system.

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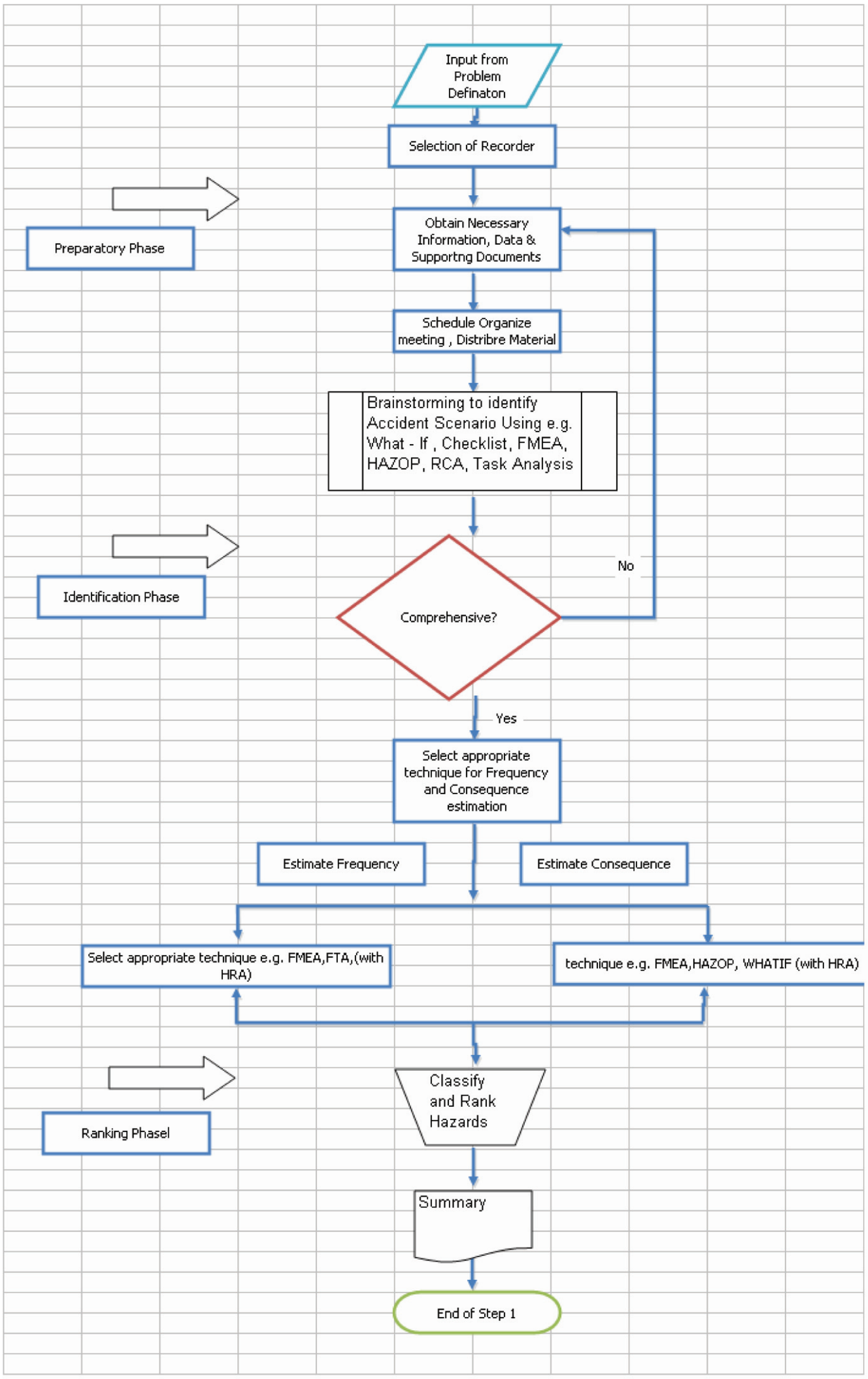
Appendix 1: Risk analysis process flow chart and Process log

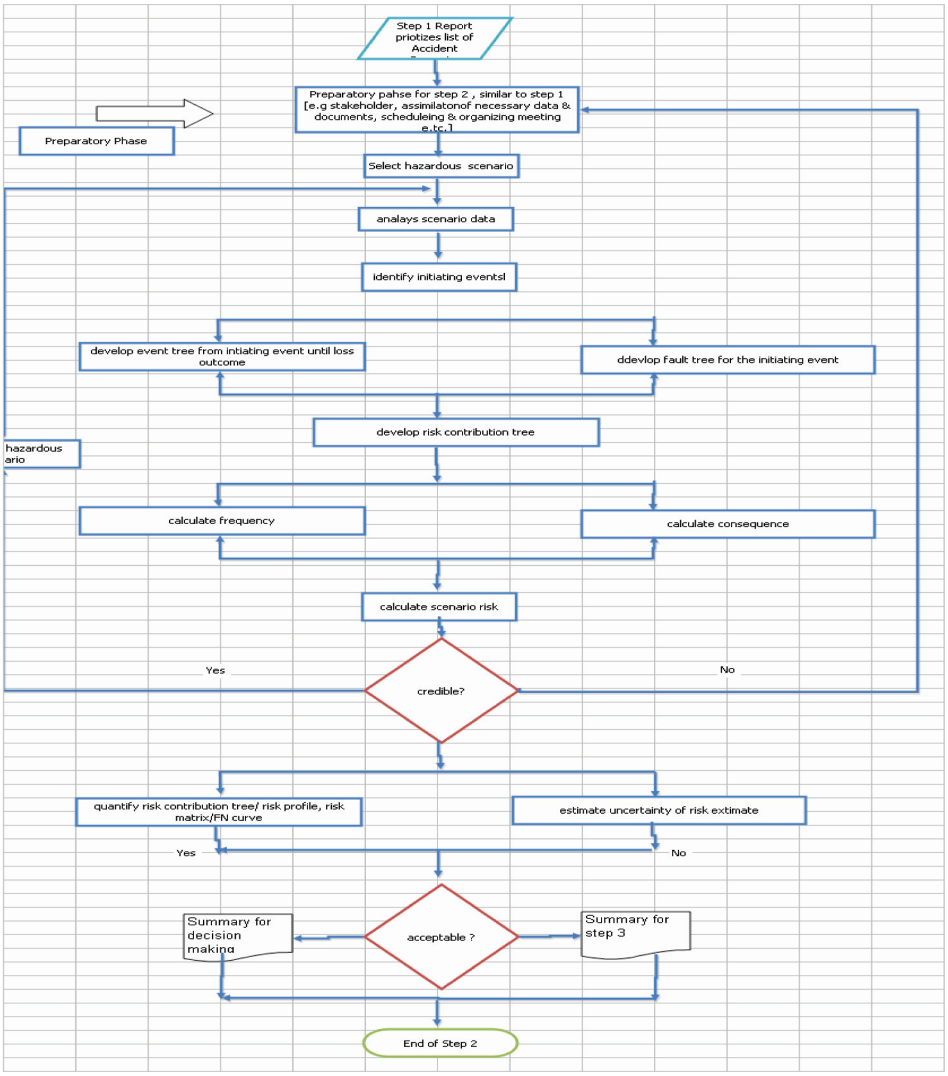
Step 1



Step 1

S/N	Activity	Input	Interacting sub-process	Critical issues	Controls	Controling measuremnet output	Output	Comment
1	Input from problem definition	Scope & detail from checklist	Making checklist	Scope of research, relevant according to rule & regulation	-	-	Scope of HAZARD IDENTIFICATION process	
	Stake holder	Profile	-	Contribution, availability	Qualification, experience, planning round table scheduling	Team structure.	HAZID facilitation	
	Select recorder	Data recording	-	Ability to capture relevant inputs	Use of software, tape-recording	Monitoring of records	Selected recorder	
	Obtain necessary information, data &supporting documents	Casualty statistic, data, expert input	Root cause analysis of accident s and incidents	Validity of the input data	Input from reputable databases and relevant experience	Convergent character of inputs	Assimilated data	
	Schedule & organize meting distribute material	ALL-engagement		Time for completion of HAZID process, cost of meeting	Selection of stand by alternative	Time for round table session	Schedule	
	Barnstorming to identify accident scenario using e.g. DELPHI, what- if / checklist, FMEA, HAZOP, RCA, Task Analysis	Casualty statistic, data , expert input	What If , checklist, FMEA, HAZOP, RCA, Task Analysis	Environmental and stake holder attitude	Evaluation of inputs	Divergent of input	Identify accident scenarios	
	Comprehensive?	Accident scenario		Divergent relevant of inputs	-	Classification of inputs	Decision contribute of process	
	Estimate frequency: select appropriate technique e.g. FMEA, FTA (with HRA)	Each accident scenarios	FMEA, FTA (with HRA)	Validity of result	Validation with reported data experience	Variation from reported data	Frequency estimate (F)	
	Estimate consequence: select appropriate technique e.g. ETA, HAZOP, WHAT-IF (with HRA)	Each accident scenarios	ETA, HAZOP, WHAT-IF (with HRA)	Validity of result	Validation with reported data experience	Variation from reported data	Consequence estimate (C)	
	Classify and rank hazards	Accident scenario(F &C)	-	Establish risk matrix, elimination of irrelevant scenario	Reported data and experience of members	% of generated scenarios	Rank scenario	
	Summary / result	Accident scenario(F &C)	-	Reasoning on ranking , clarity	Documents standards (IMO, IACS, PIANC, LUAS)	Step one summary and presentation	Output from step 1	

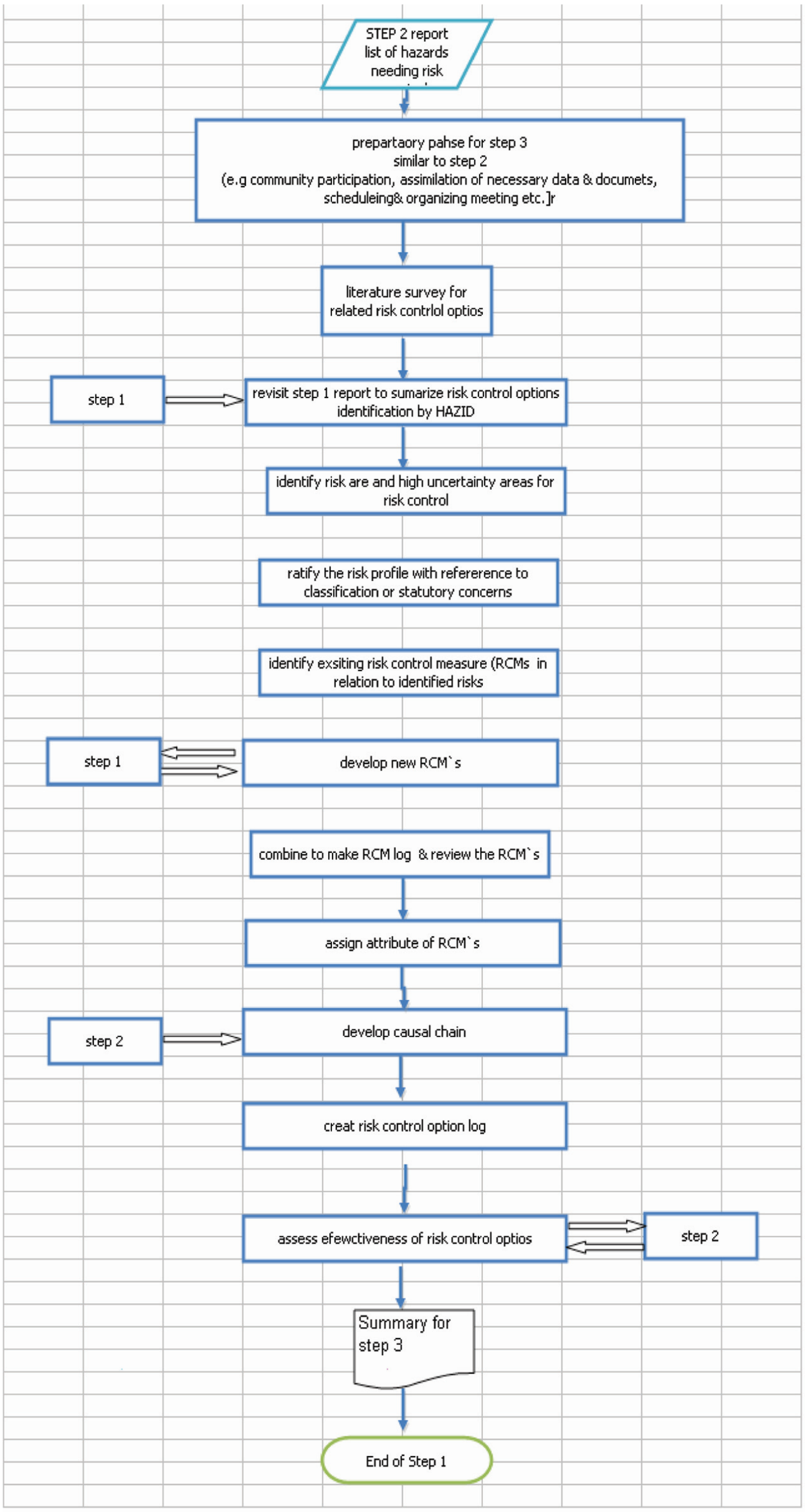
Step 2


Step 1 Report
priotizes list of
Accident
Preparatory pahse for step 2 , similar to step 1 [e.g stakeholder, assimilatonof necessary data & documents, scheduleing & organizing meeting e.tc.]
Preparatory Phase
Select hazardous scenario
analays scenario data
identify initiating eventsl
develop event tree from intiating event until loss outcome
ddevlop fault tree for the initiating event
develop risk contribution tree
hazardous
ario
calculate frequency
calculate consequence
calculate scenario risk
Yes
No
credible?
quantify risk contribution tree/ risk profile, risk matrix/FN curve
estimate uncertainty of risk extimate
Yes
No
Summary for decision making
acceptable ?
Summary for step 3
End of Step 2

Step 2

S/N	Activity	Input	Interacting sub-process	Critical issues	Controls	Controling measuremnet output	Output	Comment
1	Prioritize list of hazardous scenarios	Input from hazard identification	-	Assessment of most significant accident scenario			-	
2	Prioritize list of hazardous scenarios	Preparation phase for step 2 activities	Making checklist for step 2 assessment (Refer Indicative Checklist)	Contribution, availability of tools and stakeholders	Qualification , experience , planning and scheduling	Size , dates	Step 2 tools, team, stakeholder planning	
3	Identify hazard list scenario	Select hazard scenario		Ability to capture relevant inputs	Mapped result from step 1	-	Selected scenarios	
4	Scenario data	Analysis of scenario data of incident and accident	Root cause analysis(RCA) of accident s and incidents	Validity of input data	Input from reputed data based , relevant experience of members	Convergence characteristics of inputs	Assimilated data	
5	Scenario data, experience , step 1 details, RCA	Identifying initiative events	Grouping initiators	Correct sequence of events	Drawing up preliminary event thre	Avoidance of double counting, number of events	Identify initiating events	
6	Data experience, igniting events	Developing events three	ETA, What – if / checklist, FMEA, HAZOP,RCA, Task analysis	Common cause failures, correctness of models, domino effects	Evaluation against HAZID	Structure of event three time to construct	Event tree	
7	Data experience, initiating events	Developing fault trees	FTA FMEA	Correctness of model, assumption in system definition	Evaluation of minimal cut sets	Structure of fault tree, time to construct	Fault trees with cuts – sets	
8	Events tree and fault tree	Developing of risk contribution trees	ETA & FTA	Construct of FTA`s for initiative and critical events	Validation with reported data/ experience	-	Risk contribution three (RCT)	
9	Historical data	Calculation of frequency of events		Validation of result	Variation from reported data/ experience	-variation from reported data	Frequency estimate F	
10	Historical data	Calculation of frequency of events		Validation of result	Variation from reported data/ experience	Variation from reported data	Consequence estimate ,	
11	Scenario , F&C	Credibility check		Validation of result	Variation from reported data/ experience	Variation from reported data	Credibility scenario	
12	RCT frequency &consequences	Quantifying RCA, Risk matrix, FN CURVE	Risk matrix FN Calculation	Validation of result	Variation from reported data/ experience	Variation from reported data		
13	RCT frequency &consequences	Evaluation of uncertainty	-	Reliability estimates	Validity with reported data	Variation from reported data	Uncertainty analysis's	
`14	Risk assessment uncertainties	Acceptance of results	Reference to acceptance standard step 3 and 4	Application of acceptance standards	Validation with published data	Risk evaluation	Output from step 2	
15	Step 2 output	documentation	-	Coverage clarity	Documentation standards (IMO, IACS, PIANC)	Contents presentation	Summary	

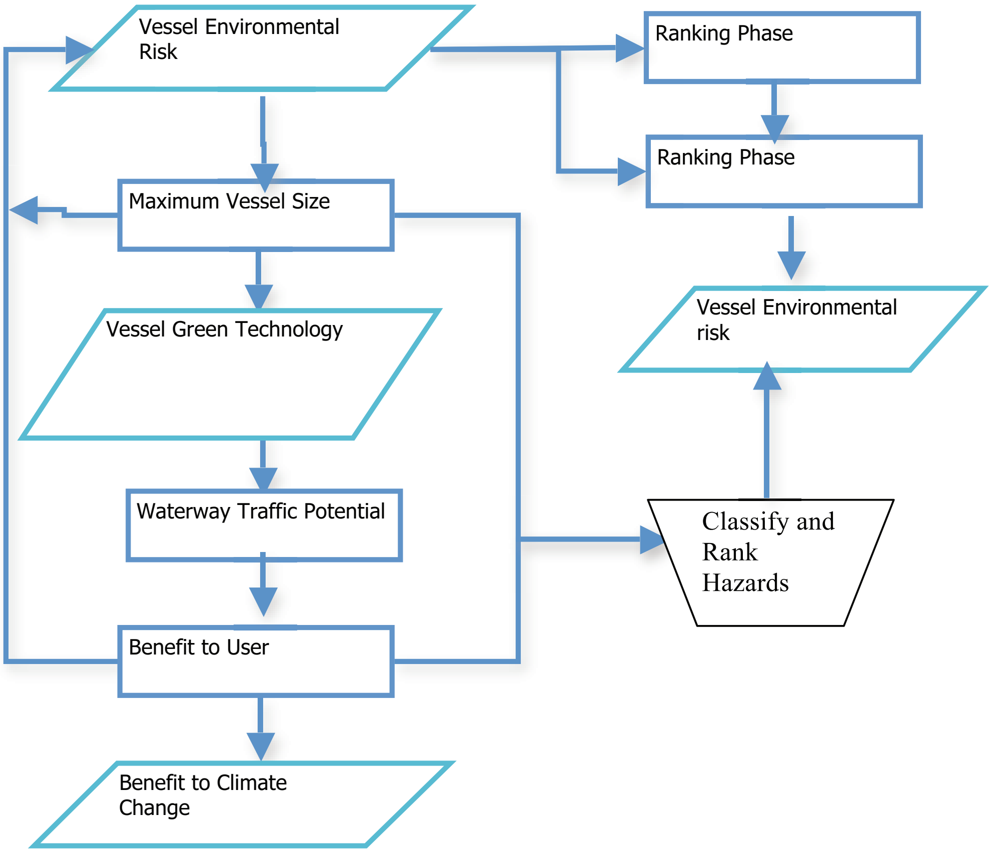
Step 3


STEP 2 report
list of hazards
needing risk
prepartaory pahse for step 3
similar to step 2
(e.g community participation, assimilation of necessary data & documets,
scheduleing& organizing meeting etc.]r
literature survey for
related risk contrlol optios
step 1
revisit step 1 report to sumarize risk control options
identification by HAZID
identify risk are and high uncertainty areas for
risk control
ratify the risk profile with refererence to
classification or statutory concerns
identify exsiting risk control measure (RCMs in
relation to identified risks
step 1
develop new RCM`s
combine to make RCM log & review the RCM`s
assign attribute of RCM`s
step 2
develop causal chain
creat risk control option log
assess efewctiveness of risk control optios
step 2
Summary for
step 3
End of Step 1

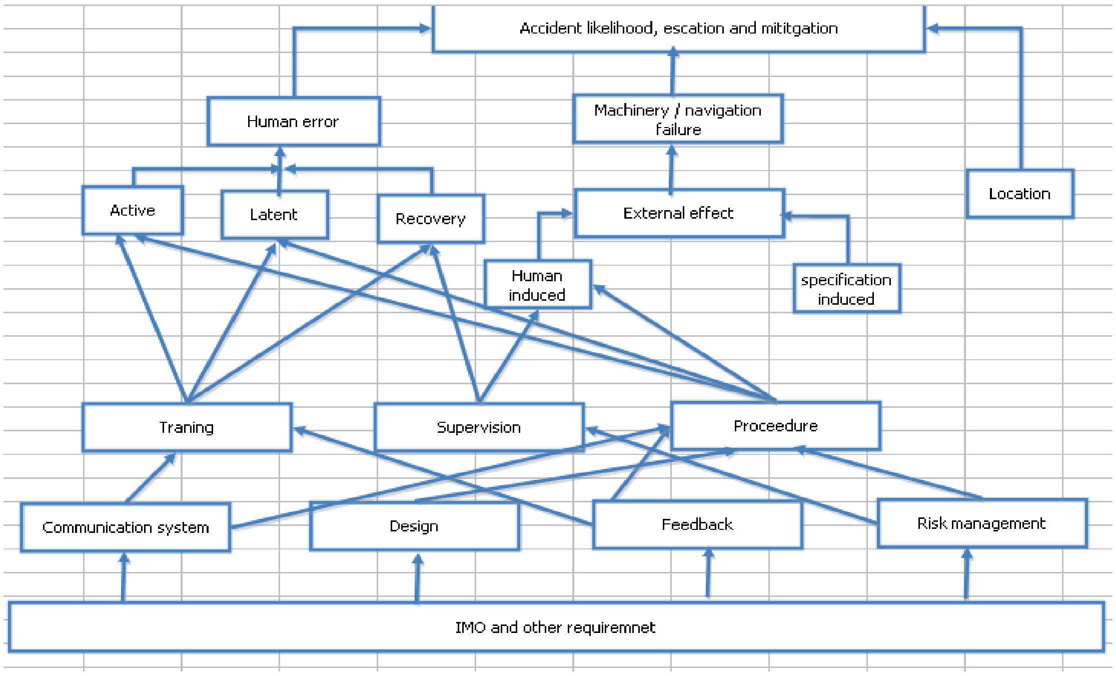
Step 3

S/N	Activity	Input	Interacting sub-process	Critical issues	Controls	Controling measuremnet output	Output	Comment
1	Preparatory phase for steps 3	List of Hazards Needing Risk Control	Making check List for step 2	Contribution members, availability of members	Experience, qualification, planning , schedule, brain storming	Constituent, proposal	Scope of HAZARD IDENTIFICATION process	
2	Literature survey for related hazards	Rules, regulations, industry practice	Data accusation theory on risk control	Establishment of base value of risk , validity of data	Quality and experience, constituents, published literature	-	background	
3	Summarize risk , control options , identify from HAZID	Step 1 Report	-	Validation of risk level in step 1 and 2	Comparison of reported risk	Risk comparability	Preliminary RCO	
4	Identify high risk area and high uncertainty area for risk control	Step 2 and step 1 report	-	High probability , high serenity and low confidence areas	Prioritize area needy control	Nodes in event trees &failures in cut-sets of FTA	Area needy control	
5	Ratify risk profile according to class statutory concerns	Hazard& rules/ regulations	-	High probability , high serenity and low confidence areas	-	-	Ratify risk profile	
6	Identify existing risk control measure (RCM)	STEP 1	Step 1 brainstorming	Flexibility / practicability, performance based/ perceptive in nature	Acceptance by team	Divergence of opinion	List of new RCMs	
7	Make RCMs Log and review	-	-	Comprehensive coverage	-	-	RCM log	
8	Assign attribute of RCMs	-	Barnstorming and sorting	Interaction between attributes	Avoiding over reliance on single category	-	RCMs with attributes	
9	Develop causal chain	Step 2	Step 2	Recognition of underlying influence	Validation with event trees	-	Pivotal events of RCMs	
10	Create risk control option log	-	Selection of approach	Practicability of regulatory option	Preventive distributed approach	Prevention/ mitigation	RCO log	
11	Assess effectiveness	Step 2	Step 2	reduction of risk/ no new risk	Risk assessment	FN Curve / risk profile	Reduction in risk	
12	Report For STEP 3	-	-	Clear & Concise Report	Reporting Standards	-	Step 3 Report	

Appendix 2: IWTS environmental and safety risk block model



Appendix 3: Regulatory and functionality influence diagram



Appendix 4: Preliminary hazard analysis

hazard element	triggering event1	hazardous condition	triggering event 2	potential accident	effect	corrective measures
kinetic energy	loss of navigation control	ship1 sail on random course	another ship is on ship1 course	collision, rupture of cargo tanks	fatalities, environmental damage, damage to hull	Improving navigational standards
kinetic energy	loss of navigation control	ship1 sail on random course	stationary obstacle on ship 1 course	power grounding , rupture of cargo tank	fatalities, environmental damage, damage to hull	
kinetic energy	Obstacle on ship1 course	retardation (i.e. reverse)	movement of unfastened material on board vessel	crushed personnel, material damage	fatalities, environmental damage	

Appendix 5: HAZOP

No	Guideword	Description	Causes	Safety measure
1	No Pitch	No rotational energy is transformed	operation , control mechanism, alignment failure	address by 2, 3, 4, 5
2	No blade	No rotational energy is transformed	Object in the water break the blade	implementation of propeller protection such as grating jet, sail in ice free water, +7& 9
3	No control bar	All blade on random pitch, loss of operational control	material weakness	improve design and construction
4	No crank wheel	On all blade have independent pitch	material weakness	improve design and construction
5	NOT enough material strength	part of propeller breakdown	wrong design, corrosion or cavitations, alignment different pitch, extra load on bearing	validate propeller design, catholic protection, appropriate propeller material, test the propeller against cavitations periodic alignment adjustment
6	MORE pitch than optimal	Too heavy load on propulsion system. Cavitations	operation failure	surveillance, increase operator competency
7	LESS pitch than optimal	Too little load on propulsion system. Cavitations	operation failure	surveillance, increase operator competency
8	LESS draft than allowed	Propeller I not sufficiently submerged. Loss of Thrust	operation failure	surveillance, increase operator competency
9	LESS depth than necessary	Propeller hit the ground and it is damaged	operation failure	technical equipment, surveillance, increase operator competency