Safety and Environmental Risk and Reliability Model for Inland Waterway Collision Accident Frequency

O. O. Sulaiman[*1], A .H. Saharuddin[2,] A. S. A. Kader[3], A. R. N. Laily[4]

Abstract**—** *Marine vessel collisions cover the largest part of accidents scenario in waterways. Waterways accidents expose vessel owners and operators, as well as the public to risk. They attract possibility of losses such as vessel cargo damage, injuries, loss of life, environmental damage, and obstruction of waterways. Collision risk is a product of the probability of the physical event its occurrence as well as losses of various nature including economic losses. Environmental problem and need for system reliability call for innovative methods and tools to assess and analyze extreme operational, accidental and catastrophic scenarios as well as accounting for the human element, and integrate these into a design environments part of design objectives. This paper discusses modeling of waterways collision risk frequency in waterways. The analysis consider mainly the waterways dimensions and other related variables of risk factors like operator skill, vessel characteristics, traffic characteristics, topographic, environmental difficulty of the transit, and quality of operator's information in transit which are required for decision support related to efficient, reliable and sustainable waterways developments. The probability per year predicted is considered acceptable in maritime and offshore industry, but for a channel using less number of expected traffic, it could be considered high. Providing safety facilities like traffic separation, vessel traffic management could restore maximize sustainable use of the channel*.

Keywords**—** collision, risk, reliability, frequency, inland waterways, environmental prevention

I. Introduction

Collision in waterways falls under high consequence incidents, collision data may be imperfect or inconstant, making it difficult to account for dynamic issues associated with vessels and waterways requirement. Accounting for these lapses necessitated need to base collision analysis on hybrid use of deterministic, probabilistic or simulation methods depending on the availability of a data. Developing sustainable inland water transportation (IWT) requires transit risk analyses of waterways components and relationship between factors such as environmental conditions, vessel characteristics, operators' information about the waterway, as well as the incidence of groundings and collisions, using available data. Whatever information is available is useful for risk and reliability based decision work of accidents rate of occurrence, consequence and mitigation [1, 7]. Risk and reliability based design entails the systematic integration of risk analysis in the design process targeting system risk prevention, reduction that meet high level goal and leave allowance for integrated components of the system including environment that will facilitate and support a holistic approach for reliable and sustainable waterways appropriate and require trade-offs and advance decision-making leading to optimal design solutions.

Frequency estimation work on channel lead to fundamental sustainable model of transit risk that include factors such as traffic type and density, navigational aid configuration, channel design and waterway configuration and classification. For cases where there are insufficient historical record to support their inclusion, more comprehensive models of transit risk will have to rely on integral use of hybrid of deterministic, probabilistic, stochastic method whose result could further be simulated or employ expert judgment to optimize deduced result [2]. Risk based collision model are derivative for improvement of maritime accident data collection, preservation and limit acceptability using information relating to the following:

i. ports for entering incidents
ii. wind speed and direction, visibility, water level, current speed and direction, etc.
iii. eliminate/correct erroneous and duplicate entries (e.g. location information)
iv. record data on actual draft and trim, presence and use of tugs, presence of pilots
v. types of cargo and vessel movements
vi. report "barge train" movements as well as individual barges
vii. improve temporal resolution (transits by day or hour)

This paper describes frequency analysis of risk based model, where accident frequency are determined and matched with waterway variables and parameter. The result hopes to contribute to decision support for development and regulation

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O. O. Sulaiman is with Faculty of Maritime Studies and Marine Science, Universiti Malaysia Terengganu, 21030 Kuala Terengganu, Terengganu, Malaysia (corresponding author):Phone 60177244339; fax6096683697; ;e-mail:o.sulaiman@umt.edu.my

A.H. Saharuddin is with Faculty of Maritime Studies and Marine Science,Universiti Malaysia Terengganu, 21030 Kuala Terengganu, Terengganu, Malaysia (e-mail: sdin@umt.edu.my)

A.S.A. Kader is with Faculty of Mechanical Engineering, Universiti Teknologi Malaysia, 81310 Skudai, Johor, Malaysia (samasak1968@gmail.com)

A.R.N. Laily is with Physical sciences Department, Faculty of Science and Technology, Universiti Malaysia Terengganu, 21030 Kuala Terengganu, Terengganu, Malaysia (liliey_nor@yahoo.com)

of inland water transportation.

II. BACKGROUND

The study area is Langat River, 220m long navigable inland water that has been under utilized. Personal communication and river cruise survey revealed that collision remain the main threat of the waterways despite less traffic in the waterways. This make the case to establish risk and reliability based model for collision aversion for sustainable development of the waterways a necessity. Data related to historical accidents, transits, and environmental conditions were collected. Accident data are quite few, this is inherits to most water ways and that make probabilistic methods the best preliminary method to analyze the risk which can be optimized through expert rating and simulation methods as required

Figure 1: Langat map

Barge and tug of capacity 5000T and 2000T are currently plying this waterway at draft of 9 and 15m respectively. Collisions (including contact between two vessels and between a vessel and a fixed structure), causes of collision linked to navigation system failure, mechanical failure and vessel motion failure are considered in this work towards design of safe and reliable the river for transportation. Safety associated with small craft is not taken into account. Below is relevant information relating to channel, vessel and environment employed in the risk process. Lack of information about the distribution of transits during the year, the joint distribution of ship size, flag particular, environmental conditions become main derivative from probabilistic estimation. In total risk management system of various methods IS used according to result expectation and performance contribution. The study use Langat River to a case study to test the model, because it is a big River with big potential that is underutilized. The testing of the model on Langat could help decision support for its development and regulation in future. Table 1 shows some of advantage associated with use o f the risk methods [3, 7]. The model described is suitable for preventive safety reliability decision for new water way development. When it is safe the environment is preserved and protected.

Table 1: Methods for risk work

Approach	Main Advantages	Main Disadvantages
Statistical method	Long been regarded as the only reliable sources	Limitation with incident reports, difficulty in application to the future
Comprehensive risk analysis	Rational, includes consequences	Relies on accident data for benchmarking
Stochastic method	Predict unfavourable conditions, inexpensive	Targets known scenarios, limits choice of software/programs, restricted to occurrence probability
Computer simulation method	Target extreme condition	Could left out certain information in real life
Expert opinions	Long been used when limited by data	Subjective

III. BASELINE DATA'S

Vessel movement, port call consists of two transits IN Langat River: one into and one out of the port. Safe transit data consider the same barge type and size for risk analysis are considered

Table 2: River Langat tributary

Channel Parameters	
Width	Depth
Maneuvering lane **Vessel Clearance** Bank suction Wind effect Current effect Channel with bends Navigationaids Pilot Tugs	tDraugh Trim Squat Exposureallowance Fresh water adjutment Maneuvering allowance Overdepth allowance depth transition Tidal alllowance

Table 3: River width and depth parameters

Design parameter		**Approach channel**	
		Straight	Bend
		98m	120m
		3-6m	3-6m
Side slope		10H:1V	10H:1V
Estuarine	135.7km	North (44.2km)	South (9.9km)

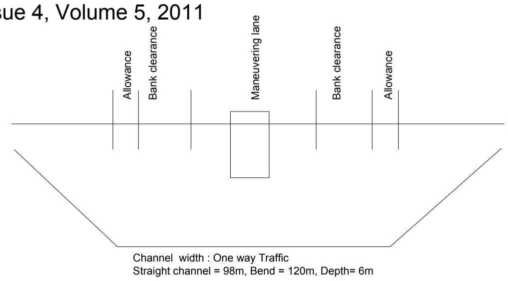


Figure 2**:** Channel width parameter

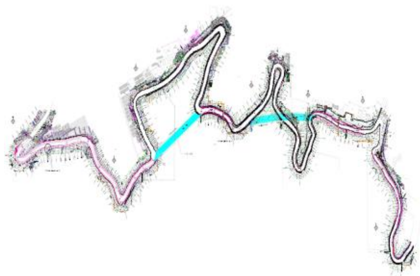


Figure 3: Channel straightening and alignment, required radius of curvature at bends for 5000 DWT, Towed barge Length = Barge Length + Tug Length + Tow Line, R> (4-6) length of barge train (to meet the navigation requirement): PIANC, 2007

Table 4: Vessel requirement: a.barge parameter

a.Barge parameter	2000 tons	5000 tons
Length (m)	67.3	76.2
Beam (m)	18.3	21.3
Depth (m)	3.7	4.9
Draft (m)	2.9	4.0

Table 5: Vessel requirement: b.tug parameter

b.Tugs parameter	2000 tons	5000 tons
Length (m)	23.8	23.8
Beam (m)	7.8	7.8
Depth (m)	3.5	3.5
Draft (m)	2.8	2.8
Horse Power (hp)	1200	1200

The main risk contributing factors can fall under the following:

i. Operator skill: there is no direct measure of this risk, inherently, highly skilled or seasoned operators, and those with better local knowledge, may be expected to produce a lower risk of accidents. Flag ship or expert rating, port policy for entrance procedure could be used, this case frequency analysis relating to collision by barge flag or operator is considered

ii. Vessel characteristics: maneuverability capability of vessel could determine probability of accident, maneuverability data is difficult to acquire in waterways that has no Automatic identification system (AIS) system in place. Therefore, analysis rely on derivative from vessel type and size, barge trains are, in general, likely to be less maneuverable than ships [4].

iii. Traffic characteristics: most wind and visibility information are hourly tracked through installed higher wind speed range which are likely from sensor located at the airport. There is potential visibility fluctuation resulting from this. [7]

iv. Topographic difficulty of the transit: the number of bent in the channel also adds to channel complexity which needs further consideration.

v. Environmental condition: this involves analysis of the effect of wind speed, visibility, and water level on accident risk. A transit characterized by unfavorable environmental conditions, such as high wind, poor visibility, or strong currents, may be expected to involve a greater risk of accidents than a transit through the same area under more favorable conditions.

vi. Water Level: Accident due to tide are much linked to grounding, we assume that there is significant correlation between collision and grounding, Figure 5 shows the distribution of predicted and observed water level, if the distribution during groundings had a larger peak in the low water level, this could be due to increased risk of groundings or large (negative) errors in the tide forecasts used by vessel operators, this could be reduced through maximization of underkeel clearance against deep draft vessel [10].

vii. Tide Forecast Error: large forecast errors resulting in lower-than-forecast actual water levels. River complexity- Figure 4 shows some of the model that is used to address various river complexities to manage safety and protect environment along Langat and it tributary. This model can be translated into benefit for reduction option.

Figure 4, 5 and 6 shows the environmental parameters considered in the risk process.

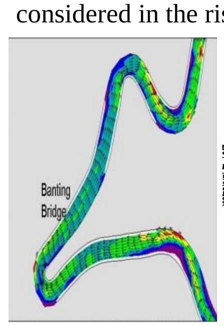


Fig. 4

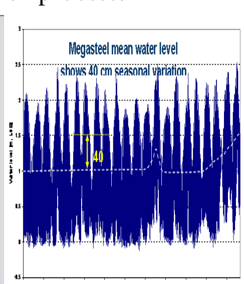


Fig.5

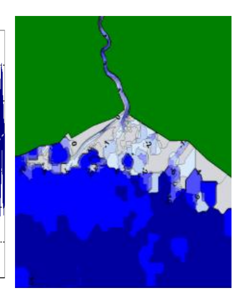


Fig.6

Figure 4: Tide movement and current EB, Green to red: low to high speed, Figure 5: Water level Mean, water level = 40cm seasonal variation, Existing coastal environmental current, Figure 6: Coastal current, Avg. Speed in Spring tide 0.4 -1.2 m/s, Avg. Speed in Neap 0.2 - 1.0 m/s

Table 6: River Models

Model	Tool	
Rainfall-Runoff model	NAM	Contribution of catchments runoff to Langat river
One-Dimensional River model	MIKE11	Establish baseline condition of tide, salinity, flood level of the Langat river Assess the impacts of navigational improvement plan
Two-Dimensional Curvilinear Grid Model	MIKE21 C	assess the impacts of navigational improvement plan on erosion/deposition pattern of the Langat river
Two-Dimensional Rectangular Grid Nested Model	MIKE21	Establish baseline condition of tide, wave, erosion/deposition pattern for Langat river mouth assess the impacts of proposed navigation improvement plan

i. Quality of operator's information: quality of operator information about environmental conditions, information about currents, tide levels, and winds can help in the risk process.

ii. Uncertainty in Surveys/Charts: it is better to use hydrostat for interpolation of the locations of the accidents as plotted on a chart. Thus that comes with bargage of point error distribution for depth survey.

iii. Real-time Environmental Information: for this it is important to use caution when comparing accident rates across ports and over time because of differences in reporting criteria. However the annual accident data collected is good for preliminary analysis using probabilistic method can give information about possible temporal factor changes [4].

iv. Frequency of accident and geographical distribution of transit through open and water approach survey could also help in analysis of uncertainty.

A. Data Collection Limitation

Limitations in data collection poised hybrid combinatory use of historical, first principle, or deterministic and stochastic analysis, future data collection effort can open opportunity for improvement in validation analysis as well as understanding of accident risk. In this case the data is good enough data to model a predictive and state space analysis model of frequency of occurrence in the channel. Major data problems are as follows:

i. Vessel Casualty Data: Inherent problem with causality data have missing entries, duplicate entries, and inaccuracies. Lack of recording of location of accidents in theory expected to be to the tenths of minute's latitude/longitude for accuracy. In reality rarely latitude/longitude information is rarely given, leading to erroneous location information. Data limitation are lack draft or trim data of vessels at the time the accident happen, actual water depth at the time of the accident from the environmental data, lack of quantification in the use of tugs and present of pilot [12].

ii. Environmental Data: Limitations are associated with potential change in real-time oceanographic data systems. Wind and visibility are general to each port area, and measured at an airport location that does not necessarily reflect conditions on the water. No historical information on currents, lack of consistency on wind and visibility, and water level and current conditions.

iii. Port-Specific Data: information about safe transits counts categorization by flag, vessel type, vessel size, with tug escort and piloting information, taken at hourly by authority.

iv. Surveys and Chart Data: it is important to compare conventional cartographic uncertainty and with new technology to cover additional uncertainties.

IV. SAFETY AND ENVIRONMENTAL RISK FOR IWT

Risk and reliability based model aim to develop innovative methods and tools to assess operational, accidental and catastrophic scenarios. It requires accounting for the human element, and integrates them as required into the design environment. Risk based design entails the systematic integration of risk analysis in the design process. It target safety and environment risk prevention and reduction as a design objective. To pursue this activity effectively, an integrated design environment to facilitate and support a holistic risk approach to ship and channel design is needed. Total risk approaches enable appropriate trade off for advanced sustainable decision making. Waterways accident falls under scenario of collision, fire and explosion, flooding, grounding.

i. Loss of propulsion
ii. Loss of navigation system
iii. Loss of mooring function and
iv. Loss of Other accident from the ship or waterways

Risk based design entails the systematic risk analysis in the design process targeting risk preventive reduction. It facilitates support for total risk approach to ship and waterways design. 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 element and system lifecycle phases.

Therefore, it becomes imperative to develop, refine, verify, validate reliable model through effective methods and tools. The risk process begins with definition of risk which stands for the measure of the frequency and severity of consequence of an unwanted event (damage, energy, oil spill). Frequency at which potential undesirable event occurs is expressed as events per unit time, often per year. The frequency can be determined from historical data. However, it is quite inherent that event that don't happen often attract severe consequence and such event are better analyzed through risk based and reliability model. Figure 3.2 shows main components of risk based design for IWT. Risk is defined as product of probability of event occurrence and its consequence.

$$\text{Risk (R)} = \text{Probability (P)} \times \text{Consequence (C)} \qquad (1)$$

Incidents are unwanted events that may or may not result to accidents. Necessary measures should be taken according to magnitude of event and required speed of response should be given. 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 could result to further loss of life, environmental damage and financial costs. The earlier stage of the process involves finding the cause of risk, level of impact, destination and putting a barrier by all mean in the pathway. Risk work process targets the following:

i Cause of risk and risk assessment, this involve system description, identifying the risk associated with the system, assessing them and organizing them in degree or matrix. IWT risk can be as a result of the following:

a. Root cause.

b. Immediate cause

c. Situation causal factor.

d. Organization causal factor

ii Risk analysis and reduction process, this involve analytic work through deterministic and probabilistic method that strengthen can reliability in system. Reduction process that targets initial risk reduction at design stage, risk reduction after design in operation and separate analysis for residual risk for uncertainty as well as human reliability factor.

Uncertainty risk in complex systems can have its roots in a number of factors ranging from performance, new technology usage, human error as well as organizational cultures. They may support risk taking, or fail to sufficiently encourage risk aversion. To deal with difficulties of uncertainty risk migration in marine system dynamic, risk analysis models can be used to capture the system complex issues, as well as the patterns of risk migration. Historical analyses of system performance are important to establish system performance benchmarks that can identify patterns of triggering events, this may require long periods of time to develop and detect. Assessments of the role of human and organizational error, and its impact on levels of risk in the system, are critical in distributed, large scale dynamic systems like IWT couple with associated limited physical oversight.

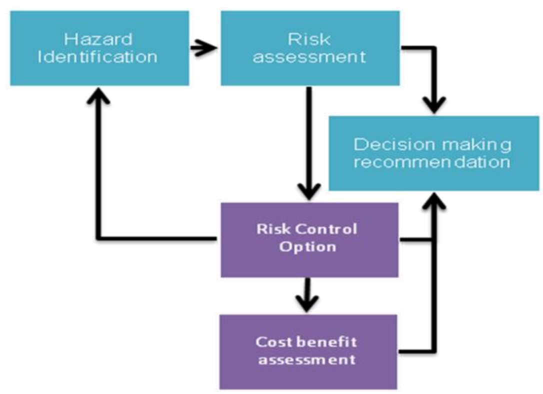
Effective risk assessments and analysis required three elements highlighted in the relation below.

$$\text{Risk modeling} = \text{Framework} + \text{Models} + \text{Process} \qquad (2)$$

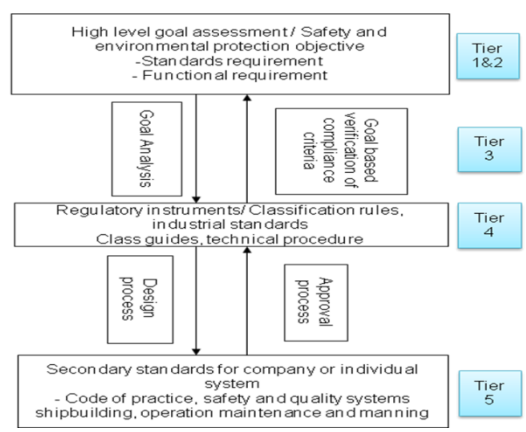
Reliability based verification and validation of system in risk analysis should be followed with creation of database and identification of novel technologies required for implementation of sustainable system.

A. Risk Framework Eq.3.1

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 understanding the manner in which accidents, their initiating events and their consequences occur. This includes assessment of representation of system and all linkage associated risk related to system functionality and regulatory impact (See Figure 7 a and b)



7(a)



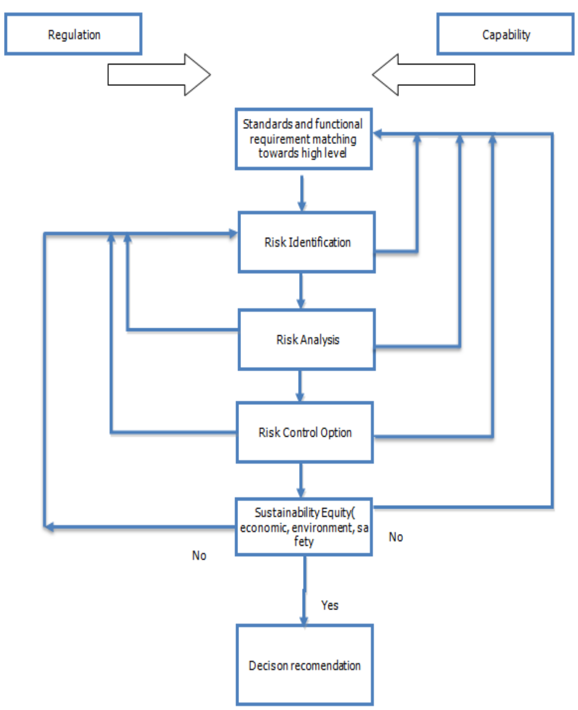
7(b)

Figure 7 a and 7b: IMO Risk framework

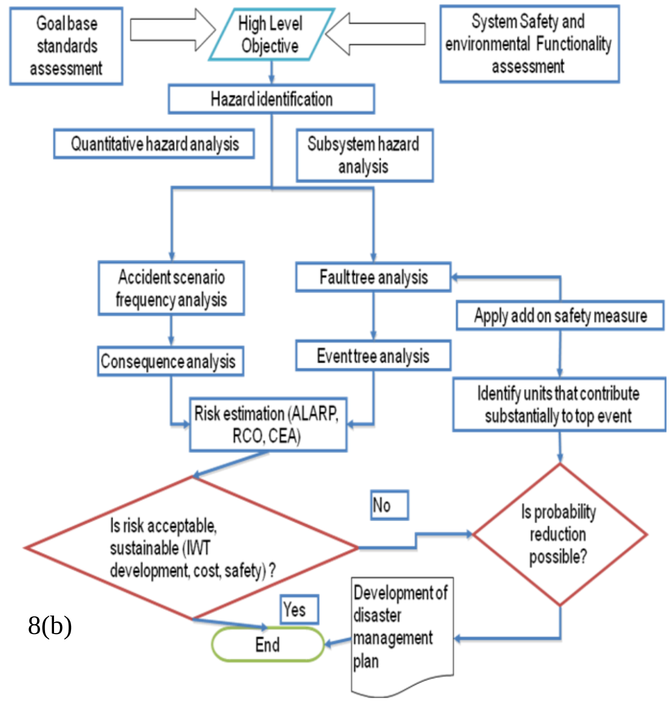
Risk framework should be developed to provide effective and sound risk assessment and analysis. The process requires accuracy, balance, and information that meet high scientific standards of measurement. The information should meet requirement to get the science right and getting the right science. The process requires targeting interest of stakeholder including members of the port and waterway community, public officials, regulators and scientists. Transparency and community participation helps ask the right questions of the science and remain important input to the risk process, it help checks the plausibility of assumptions and ensures that synthesis is both balanced and informative. Employment of quantitative analysis with required insertion of scientific and natural requirements provide analytical process to estimate risk levels, and evaluating whether various measures for risk are reduction are effective.

B. Safety and Environmental Risk and Reliability Model (SERM)

There is various risk and reliability tools available for risk based methods that fall under quantitative and qualitative analysis. Choice of best methods for reliability objective depends on data availability, system type and purpose. However employment of hybrid of methods of selected tool can always give the best of what is expect of system reliability and reduced risk. Figure 8 (a) and (b) shows generic risk model flowchart



8 (a)



8(b)

Figure 8 a and b: Risk and Reliability model flowcharts

C. SERM Process

SERM intend to address risks over the entire life of the complex system like IWT system where the risks are high or the potential for risk reduction is greatest. SERM address quantitatively, accident frequency and consequence of IWT. Other risk and reliability components include human reliability assessment which is recommended to be carried out separately as part of integrated risk process. Other waterways and vessel requirement factors that are considered in SERM model are:

i. Construction
ii. Towing operations and abandonment of ship
iii. Installation, hook-up and commissioning
iv. Development and major modifications

Integrated risk based method combined various technique as required in a process. Table 6 shows available risk based design for techniques. This can be applied for each level of risk. Each level can be complimented by applying causal analysis (system linkage), expert analysis (expert rating), and organizational analysis (Community participation) in the risk process. Figure 7 shows stakes holder that should be considered in risk process. From Figure 2, the method use is risk analysis that involves frequency analysis where the system is modeled with hybrid of deterministic, probabilistic and stochastic process.

Table 6: Risk based design techniques

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

Technically, the process of risk and reliability study involves the following four areas:

i. System definition of high goal objective: This requires defining the waterways by capturing gap between system functionality and standards. The scope of work for safely and environment risk and reliability analysis should define the boundaries for the study. Identifying which activities are included and which are excluded, and which phases of the system's life are to deal with.

ii. Qualitative hazard identification and assessment: It involves hazard identification through qualitative review and assessment of possible accidents that may occur, based on previous accident as well as experience or judgment of system users where necessary. Though, using selective and appropriate technique depends on the range, magnitude of hazards and indicates appropriate mitigation measures.

iii. Quantitative hazard frequency and consequence analysis: once the hazards have been identified and assessed qualitatively. Frequency analysis involves estimation of how likely it is for the accidents to occur. The frequencies are usually obtained from analysis of previous accident experience, or by some form of analytic modelling employed in this thesis. In parallel with the frequency analysis and consequence modelling evaluates the resulting effects of the accidents, their impact on personnel, equipment and structures, the environment or business.

iv. Risk acceptability, sustainability and evaluation: Is the yardsticks to indicate whether the risks are acceptable, in order to make some other judgment about their significance. This begins by introducing non technical issues of risk acceptability and decision making. In order to make the risks acceptable. The benefits from these measures can be evaluated by iterative process of the risk analysis. The economic costs of the measures can be compared with their risk benefits using cost benefit analysis leading to results of risk based analysis. This input necessities to the design or ongoing safety management of the installation, to meet goal and objectives of the study.

The process of risk work can further be broken down into the following elements:

i. Definition and problem identification
ii. Hazard and consequence identification
iii. Analysing the likelihood's of occurrence
iv. Analyzing consequences
v. Evaluation of uncertainty
vi. Risk control option (RCO) and risk control measure (RCM
vii. Sustainability of (cost safety, environment, injury, fatality, damage to structure, environment) and risk acceptability criteria
viii. Reliability based model verification and validation: statistical software, triangulation, iteration.
ix. Recommendation for implementation: Implement, establishing performance standards to verify that the arrangements are working satisfactorily and continuous monitoring, reviewing and auditing the arrangements

Employment of these benefit provide a rational. Formal environmental protection structure and process for decision support guidance and monitoring about safety issues. The scope of sustainable risk based design under consideration involves stochastic, analytic and predictive process work leading to avoidance the harms in waterways. Figure 8 shows block diagram of SERM components for IWT. Safety and Environmental Risk and Reliability Model (SERM) for IWT required having clear definition of the following issues:

i. Personnel, attendance
ii. Identify activities
iii. Vessel accidents including passing vessel accident, crossing , random
iv. Vessel location and waterway geography on station and in transit to shore.
v. Impairment of safety functions through determination of likelihood of loss of key safety functions lifeboats, propulsion temporary refuge being made ineffectiveness by an accident.
vi. Risk of fatalities, hazard or loss of life through measure of harm to people and sickness.
vii. Property damage through estimation of the cost of clean-up and property replacement.
viii. Business interruption through estimation of cost of delays in production.
ix. Environmental pollution may be measured as quantities of oil spilled onto the shore, or as likelihood's of defined categories of environmental impact or damage to infrastructures.

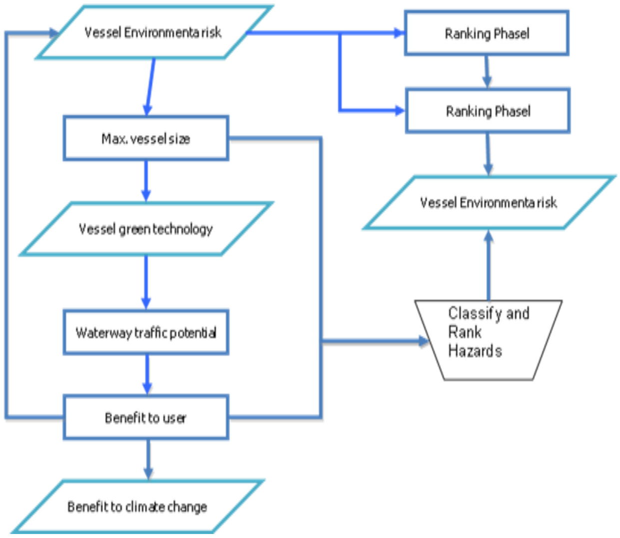


Figure 9: IWT safety and environmental model components block diagram

Allowance should be made to introduce new issue defining the boundary in the port from time to time. The choice of appropriate types of risk tool required for the model depend on the objectives, criteria and parameter that are to be used. Many offshore risk based design model consider loss of life or impairment of safety functions. There is also much focus on comprehensive evaluation of acceptability and cost benefit that address all the risk components. Figure 9 shows the risk and reliability model combined process diagram. The analysis is a purely technical risk analysis. When the frequencies and consequences of each modeled event have been estimated, they can be combined to form measures of overall risk including damage, loss of life or propulsion, oil spill. Various forms of risk presentation may be used. Risk to life is often expressed in two complementary forms. The risk experienced by an individual person and societal risk. The risk experienced by the whole group of people exposed to the hazard (damage or oil spill).

Accident and incident are required to be prevented not to happen at all. The consequence of no safety is a result of compromise to safety leading to unforgettable loses and environmental catastrophic. Past engineering work has involved dealing with accident issues in reactive manner. System failure and unbearable environmental problem call for new proactive ways that account for equity requirement for human, technology and environment interaction. The whole risk assessment and analysis process starts with system description, functionality and regulatory determination and this is followed by analysis of:

i. Fact gathering for understanding of contribution factor
ii. Fact analysis of check consistency of accident history
iii. Conclusion drawing about causation and contributing factor
iv. Countermeasure and recommendation for prevention of accident

Most risk based methods define risk as:

Risk = Probability (Pa) x Consequence (Ca) (3)

or in a more elaborate expression risk can be defined as:

Risk = Threat x Vulnerability x {direct (short-term) consequences + (broad) Consequences} (4)

In risk analysis, serenity and probability of adverse consequence hazard are deal with through systematic process that quantitatively measure , perceive risk and value of system using input from all concerned waterway users and experts.

Risk can also be expressed as:

Risk = Hazard x Exposure (5)

Where hazard is anything that can cause harm (e.g. chemicals, electricity, Natural disasters), while exposure is an estimate on probability that certain toxicity will be realized. Severity may be measured by No. of people affected, monetary loss, equipment downtime and area affected by nature of credible accident. Risk management is the evaluation of alternative risk reduction measures and the implementation of those that appear cost effective where:

Zero discharge or negative damage = Zero risk (6)

The risk and reliability model subsystem in this thesis focus on the following identified four risks assessment and analysis application areas that cover hybrid use of technique ranging from qualitative to qualitative analysis (John, 2000):

i. Failure Modes Identification Qualitative Approaches
ii. Index Prioritisation Approaches
iii. Portfolio Risk Assessment Approaches, and
iv. Detailed Quantitative Risk Assessment Approaches.

V. COLLISIONS RISK MODELLING

Collision in waterways is considered low frequency and high consequence events that have associative uncertainty characteristics / component of dynamic and complex physical system. This makes risk and reliability analysis the modest methods to deal with uncertainties that comes with complex systems. Employment of hybrid deterministic, probabilistic and stochastic method can help break the barriers associated with transit numbers data and other limitation. Conventionally, risk analysis work often deal with accident occurrence, while the consequence is rarely investigated, addressing frequency nd consequence analyze can give clear cuts for reliable objectives. Risk and reliability based design can be model by conducting the following analysis that includes the following process [13, 16]:

i. Risk identification
ii. Risk analyses
iii. Damage estimation
iv. Priotization of risk level
v. Mitigation
vi. Repriotization of exposure category: mitigate risk or consequence of events that meet ALARP principle.
vii. Reassess high risk events for monitoring and control plans.
viii. Recommendation, implementation, continuous monitoring and improvement.

Collision is likely to be caused by the following factors shown in Figure 10 derived from fault three analyses from RELEX software. The RELEX software is based on fault three analyses where consequence of causal events are add up through logic gate to give minimum cut set probability that trigger the event. It is more effective for subsystem analysis.

P (collision) = P (propulsion failure) + P (loss of navigation failure) + P (Loss of vessel motion) (7)

There is also causes are mostly as a result of causes from external sources like small craft, are cause of cause, cause from other uncertainty including human error may attract separate subsystem analysis.

A. Collision data

Collision data are drawn from relevant marine administrator; there is expectation that most data gaps can be covered by the probability estimations. The Langat River work model risk through systemic analysis procedures for sustainable inland waterways transportation. It determine the probability of failure or occurrence, risk ranking, damage estimation, high risk to life safety, cost benefit analyze, sustainability and acceptability criteria [5, 14]. The study analyze causal accidental relating to navigational, mechanical failure and human error and ignored those identified as intentional for barge and tugs of 5000T and 2000T having respective drift of draft greater than 9 to 15m. Table 7 shows some of the annual traffic summary, collision and the consequences on Langat. Seasonal trends can be stochastically modeled from probabilistic result, environmental condition and traffic volume fluctuation is also considered negligible. For visibility, navigation is considered to be more risky at night than day time, the analysis follow generic assumption for evenly safe distribution evenly during day and night.

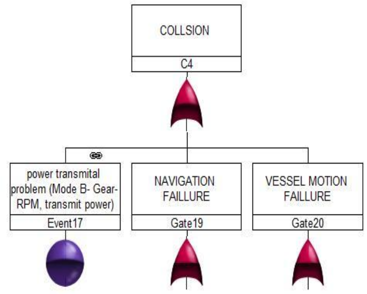


Figure 10: Collision contributing factor

Figure 11: Tugs puling large in Langat (RELEX)

A critical review of risk assessment methodologies applicable to marine systems reiterate that the absence of data should not be used as an excuse for not taking an advantage of the added knowledge that risk assessment can provide on complex systems [6]. Approximation of the risks associated with the system can provide a definition of data requirements. The treatment of uncertainty in the analysis is important, and the limitations of the analysis must be understood. However, data management system and better approach can always accommodate little data or no data. Table 6 shown models that have been used design of system based on risks in marine industry.

Table 6: 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 a spill consequence assessment model	Oil spill assessment limited to use of fault tre
Sirkar *et al* (1997)	Monte Carlo technique to estimate damage AND 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 Center (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

IMO and Sirkar *et al* (1997) methods lack assessment of the likelihood of the event, likewise other model lack employment of stochastic method whose result could cover uncertainties associated with dynamic components of channel and ship failure from causal factors like navigational equipment, training and traffic control[14]. Therefore, combination of stochastic, statistical and reliability method based on combination of probabilistic, goal based, formal safety assessment, deterministic methods and fuzzy method using historical data's of waterways, vessel environmental, first principle deterministic and traffic data can deliver best outcome for predictive, sustainable, efficient and reliable model for complex and dynamic system like inland water transportation. The general hypothesis behind assessing physical risk model is that the probability of an accident on a particular transit depends on a set of risk variables require for analysis of prospective reliable design. Figure 7, 8 and 9 show traffic data utilized in the model. Most of the method above used historical data, the novel method in this paper used limited data of traffic used to model the physics of the system, the transfer function and stochastically project accident frequency. The projection is generic and can be used for any waterways and it consider random collision not which is not considered by previous model.

Table 7: Tug boat & vessel activities along river for 2008

Jetty	3 nos.
Daily	9 times.
Weekly	63 times.
Monthly	252 times.
Annually	3024 times.

Total number of barge	**Time**	**Traffic**
12	Every day (24 hrs.)	
6	(every 4 hrs)	Incoming
6	(every 4 hrs)	outgoing

Table 8: Vessel traffic, Table 9: Common to traffic

ALL Speed	2 – 3 knots
Traffic	ALL single way traffic
Lay -bys	Proposed four locations for Lay-bys

B. Traffic Frequency Estimation Modeling

Traffic density of meeting ship, ρ

$$\rho = \frac{N_m}{v.T.W} \quad \text{Ships}/m^2 \qquad (8)$$

Where Nm is number of ships frequenting the channel, v is speed of the ship, T= time of traffic activities per annum and W is width of the channel.

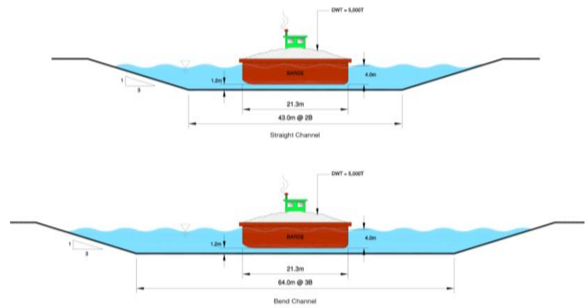
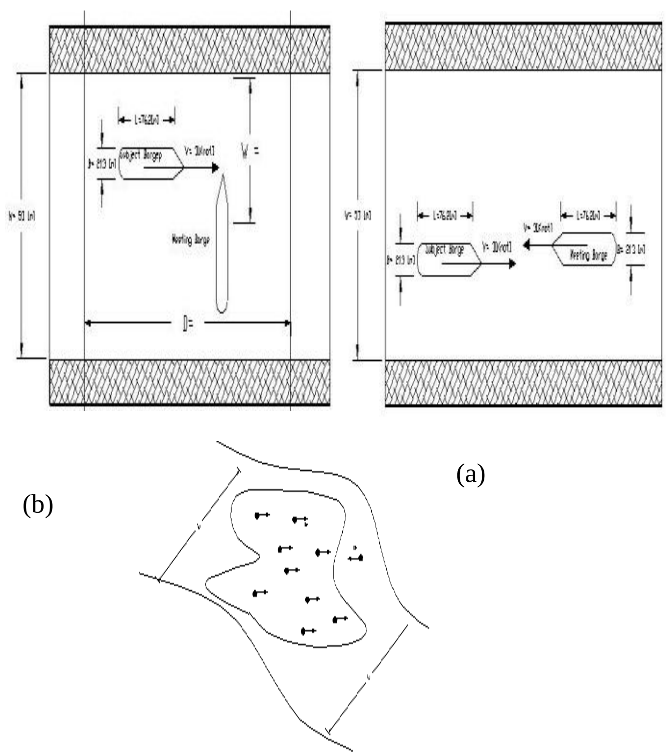


Figure 13: 5000 barge data and Langat waterway

C. Analysis of Present Situation

Traffic situation: Below are representation of various collision situations for head- on, overtaking and crossing (angle) collision scenario (see figure 14).

Where: B1 = mean beam of meeting ship (m), V1 = mean speed of meeting ship (knots), B2 = beam of subject ship (m), V2 = speed of subject ship (knots), Nm = arrival frequency of meeting ships (ship/time), D= relative sailing distance.
Expected number of collision Ni= 9.6.B.D.ρ_s = 1/passage.



(a)

(b)

(c)

Figure 14 a, b, c: Collision situations, a. overtaking, b. passing cases, c. Random

Eq. 2

Table 10, 11, and 12 shown, relevant data from previous analysis

Table 10: Expression for collision situation

Expression	Head – on	Overtaking	Random
Basic	4 x B X D x ρ_s	$\frac{(B_1+B_2)}{W} \cdot \frac{(V_1+V_2)}{V_1 . V_2}$. D. N_m	$N_i = \frac{N}{\tau . V}$. ($\frac{4}{\pi}$ * L +2*B)
Standardized	4 x B X D x ρ_s	$\frac{(B_1+B_2)}{W} \cdot \frac{(V_1+V_2)}{V_1 . V_2}$. D. N_m	9.6.D. ρ_n .B
Relative	1	1	2.4

L=6B, D=W, $N_i = P_i$ (9)

Necessary period for ship to pass the fairway T=D/v=3000/3= 1000sec (10)

Table 11 and 12 shows primary data for approximation

Table 11: Failure per nautical mile and failure per passage for collision situation (Lewiston, 1978)

	μ_c (failure per nautical mile or hour)	Pc (failure per passage or encounter
Head on	2.5 x10^{-5}	2.7.x10^{-5}
Overtaking	1.5 x10^{-5}	1.4.x10^{-5}
Crossing	1.5 x10^{-5}	1.3 .x10^{-5}

Therefore average Pc and μ_c = 2.5 x10^{-5} for random (11)

Probability of loosing navigation control within the fairway

Pc =$\mu_c . T$ failure / passage (12)

Table 12: Failure per nautical mile and failure per passage for different waterways (Fujii, 1982)

Fairway	μ_c (failure per nautical mile or hour)	Pc (failure per passage or encounter
UK	2.5 x10^{-5}	1.x10^{-4}
US	1.5 x10^{-5}	1.4.x10^{-5}
Japan	3.0 x10^{-5}	1.3.x10^{-5}

Probability of collision Pa= (Pi. Pc collision / passage) (13)

Collision per annual (Na) = Pa. N_m Collision per year (14)

In the frequency analysis, the annual frequency of each failure case is estimated. Separate frequencies are estimated for each operating phase as required. In modelling the development, consequences and impact of the events, each failure case is split into various possible outcomes. the outcomes are the end events on an event tree or chain of event trees. Each outcome probability is estimated by combining the probabilities for appropriate branches of the event tree.

The outcome frequency (Fo) is then:

$$F_o = F_e \prod P_b \quad (15)$$

Where, F_e is failure frequency, P_b probability of one segment,

Not all possible outcomes are modelled. Representative scenarios are selected for modelling, and the scenario frequency is taken as:

$$F_s = \sum_{outcomes} F_o \quad (16)$$

Failure per nautical mile and failure per passage can be selected from previous representative work. Necessary period for ship to pass the fairway T=D/v = 3000/3 = 1000 sec.

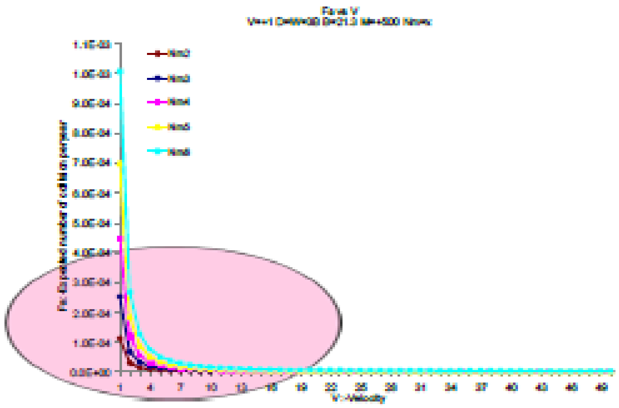
The result of accident frequency (Fa) can be compare with acceptability criteria for maritime industry. If it is two high the system could be recommended to implement TSS. If the result is high TSS can be model to see possible reduction due to its implementation. Table 13 shows frequency risk acceptability criteria for maritime and offshore industry.

Table 13: Frequency acceptability criteria

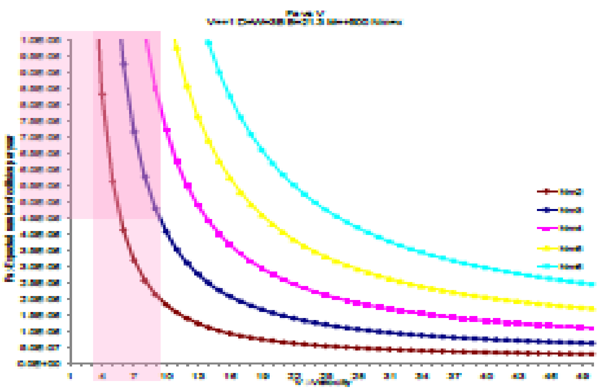
Frequency classes	**Quantification**
Very unlikely	once per 1000 year or more likely
Remote	Eq 7 once per 100- 1000 year
Occasional	once per 10- 100 year
Probable	once per 1- 10 years
Frequent	more often than once per year

C. *Frequency Analysis Result*

This result indicates that the collision in Langat is not risk on ALARP graph. Accident per year of 5.3E-5 is observed for current 3 number of vessel operating at speed of 3 knot. But physical observation revealed that there is significant and exception increase in collision that needs to be address for a channel with less traffic density. It is also observed from the plot of frequency Vs speed that when traffic density is changing traffic density of 5 and 6 and speed up to 5 considered to be cause high risk of accident frequency in the waterway (See Figure 15).



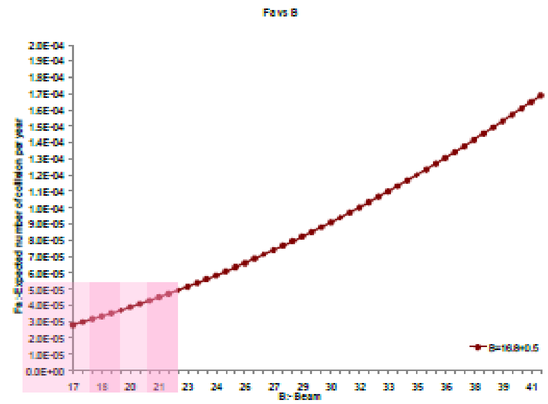
(a)



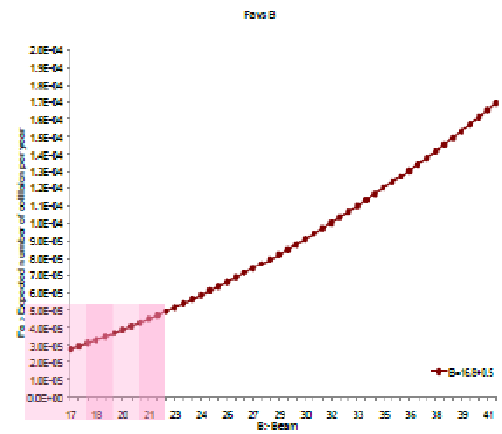
(b)

Figure15: Accident frequency Vs at changing number of ship

Figure 16 shows accident frequency at changing width and beam of the channel. Risk is acceptable for accident per 10, 000 year, if proposed maintenance of channel improvement plan is implemented. The maximum speed is round 10 knot for width of 64m and probability of 1/1000 years, other speed above this are intolerable. As width of the channel decrease there is higher risk -> Accident frequency probability increase. The maximum width considered for Langat River is 64; this width is considered too small and risky for the channel for accident per 1000 years. Different speed should be advised to ship for such situation. Width of channel can change as a result of erosion. Increasing channel width to 250m could allow speed of 20 knot at acceptable Fa (Na) of 1x10E-4. Ship operating at Langat at 3 knot at River Langat, is considered not high risk for accident per 100, 000 years. The regression equation for the trend is represented by y is 2E-08x + 1E-05 @ R^2 is 1. Similar trend is observe for Figure 12b, the beam and width are related according to PIANC W=3B AND L=6B. Table 14 shows regression equations for the frequency analysis



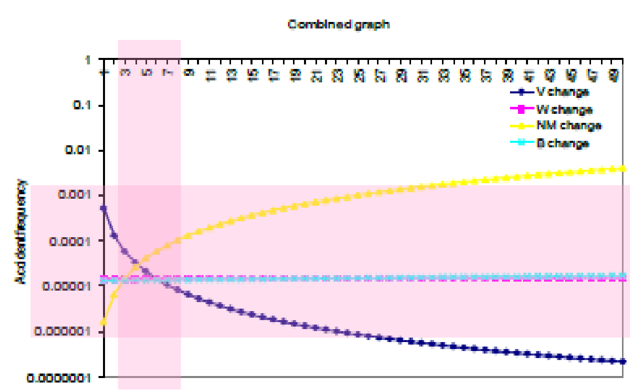
(a)



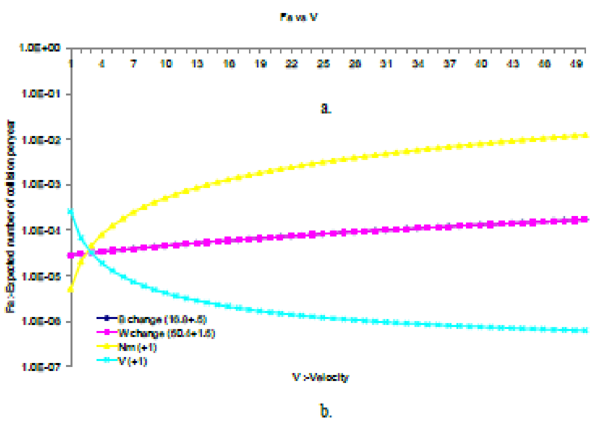
(b)

Figure 16: Accident frequency Vs beam and width of the channel

Figure 17a and b shows cross plotting of the channel variable, both plots are the same, the defence is that Figure 12b is logged because of large number shows the risk level for all channel parameters variables (speed, width, number of ships, and beam of ship). It is observed that the maximum of ship can up to 4, at the point where speed and Number of ship curves meet, provided all channel and vessel safety parameters are in place.



(a)



(b)

Figure17: cross plotting of channel variables (speed, width, number of ships, and beam of ship)

Frequency model				
Fa	@Nm changing Speed	$y = 2E\text{-}05e^{-0.11x}$	$R^2 = 0.826$	Exponential
Fa	@V	$y = 2E\text{-}05e^{-0.11x}R^2 = 0.826$	$R^2 = 1$	Square
Fa	W	y = 2E-08x + 1E-05	$R^2 = 1$	Square
Fa	B	y = 9E-07x + 0.000	$R^2 = 0.999$	Linear

Figure 18 shows number of expected collision (Ne=Ni) vs collision impact angle, since high impact is associated with high speed , the result show that high impact is likely to occur at angle between 105 -115 degree at for al speed at Ni=Ne= 2.9E-5.

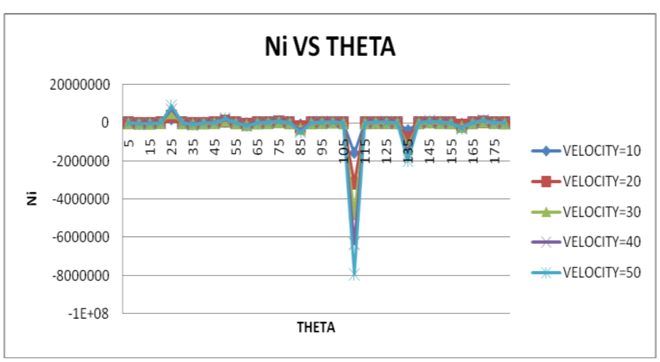


Figure 18: Impact Vs Angle, Highest impact expected at v= 50 and collision angle between 105-115l

VI. UNCERTAINTY AND SYSTEM COMPLEXITY ANALYSIS

A. *Subsystem Level Analysis*

For total risk work the following analysis could perform separately as part of subsystem risk level analysis:

i. Power transmission,
ii. navigation,
iii. vessel motion and
iv. human reliability,

subsystem level analysis can be facilitated by using frequency calculation through Fault Tree Analysis (FTA) modeling involve top down differentiation of event to branches of member that cause them or participated in the causal chain action and reaction. While consequence calculation can be done by using Event Tree Analysis (ETA), where probability is assigned to causal factor leading to certain event in the event tree structure.

B. *Channel Complexity analysis*

Channel complexity that could be addressed in the risk and reliability work are visibility weather, squat, bridge, river bent and human reliability. Figure 19 show channel complexity for Langat. Poor visibility and the number of bend may increase in the risk of and collisions. A model extracted from Dover waterway studies concluded with the following:

Fog Collision Risk Index (FCRI) = $(P_1+VI_1+P_2+VI_2+P_3 \cdot VI_3)$ (17)

Where: P_k = Probability of collision per million encounters, VI_k = Fraction of time that the visibility is in the range k, K = Visibility range: clear (>4km), Mist/Fog (200m- 4km), Tick/dense (less than 200m).

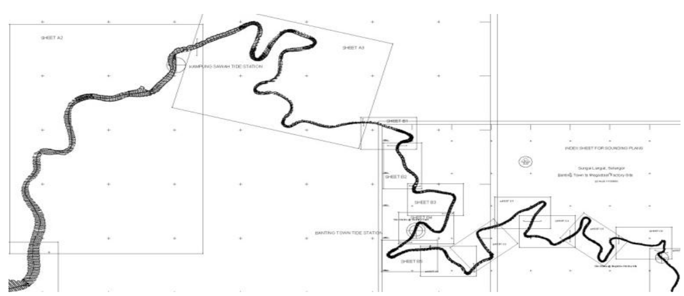


Figure 19: Langat channel complexity

Empirically derived means to determine the relationship between accident risk, channel complexity parameters and VTS is given by equation

$$R = -0.37231-35297C+16.3277N+0.2285L - 0.0004W+0.01212H+0.0004M \quad (18)$$

For predicted VTS consequence of 100000 transit, C = 1 for an open approach area and 0 otherwise, N = 1 for a constricted waterway and 0 otherwise, L = length of the traffic route in statute miles, W = average waterway/channel width in yards, H = sum of total degrees of course changes along the traffic route, M = number of vessels in the waterway divided by L.

Barge movement creates very low wave height and thus will have insignificant impact on river bank erosion and generation of squat event. Speed limit can be imposed by authorities for wave height and loading complexity. Human reliability analysis is also important to be incorporated in the channel; complexity risk work, this can be done using questionnaire analysis or the technique of human error rate prediction THERP probabilistic relation.

$$P_{EA} = HEP_{EA} \cdot \textstyle\sum_{k=1}^{m} FPS_k \cdot W_k \cdot + C \quad (19)$$

Where: P_{EA} = Probability of error for specific action, HEP_{EA} = Nominal operator error probability for specific error, PSF_k = numerical value of kth performance sapping factor, W_k = weight of PSF_k(constant), m=number of PSF, C= Constant

C. *Reliability Based Validation*

Reliability analysis is designed to cater for uncertainty and to provide confident on the model. It is important for this to be carried out separately. Reliability work could include projection for accident rate for certain number of year the following techniques:

1. Accident mean, variance and standard deviation from normal distribution

For 10 years =>Mean (μ) = 10 x Na (20)

Variance (σ) = 10 x Na x (1-Na), Standard deviation = $\sqrt{\sigma}$, Z = (X-μ)/ σ (21)

2. Stochiatic process using poison distribution, Year for system to fail from binomial, mean time to failure and poison distribution. Or determination of exact period for next accident using binomial function. Ship collisions are rare and independent random event in time. The event can be considered as poison events where time to first occurrence is exponentially distributed

$$F_r\,(N/\gamma, T) = e^{\gamma.T}(\,)\gamma,(\gamma.T)^N\,) \,.\, N! \quad (22)$$

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.

$$L(K/N,P) = \binom{N}{P} P^K (1-P)^{N.K} \quad (23)$$

Where average number of occurrence is NP

3. Comparing the model behavior apply to other rivers of relative profile and vessel particular

4. Triangulating analysis of sum of probability of failure from subsystem level failure analysis.

5. Implementation of TSS is one of the remedies for collision risk observed and predicted in Langat; this can be done through integration of normal distribution along width of the waterways and subsequent implementation frequency model. And the differences in the result can reflect improvement derived from implementation of TSS. Figure 20 shows the impact of waterways variables on implementation of TSS. The revealed that beam of ship play important role in implementation of TSS. Optimum beam is representing by the meeting point of the variables.

$$f_{south}(x) = \frac{1}{\mu\sqrt{2\pi}} e^{-\frac{1}{2}}(x - \frac{12}{\mu}) \quad (24)$$

Eq. 14

$$f_{north}(x) = \frac{1}{\mu\sqrt{2\pi}} e^{-\frac{1}{2}}(x - \frac{12}{\mu}) \quad (25)$$

.

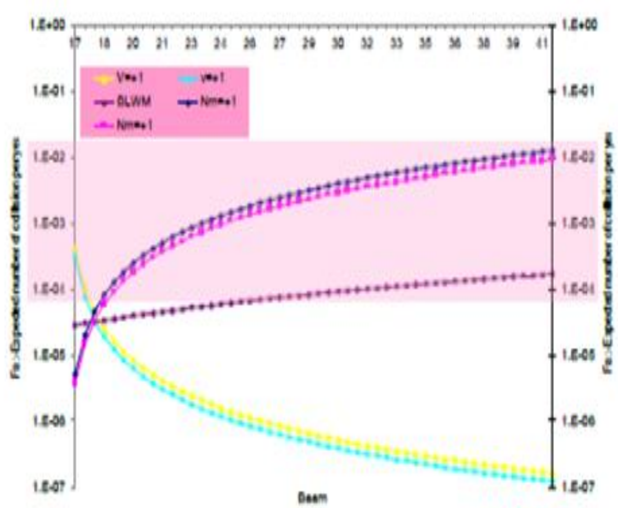


Figure 20: TSS

Variables behavior in implementation of TSS is shown above. The meeting Point signified the right beam for the ship to be safe for TSS. The beam plays a very important role in the implementation of TSS.

6. Safety level and cost sustainability analysis. Figure 21 shows the best accident frequency that is acceptable,. Ct is the total cost, Co is the cost of damage, and Cc is the cost of repair.

Eq. 17

Eq. 18

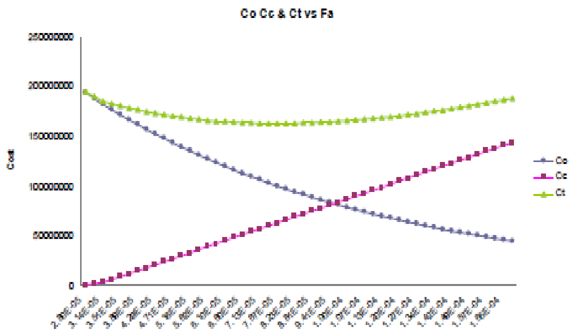
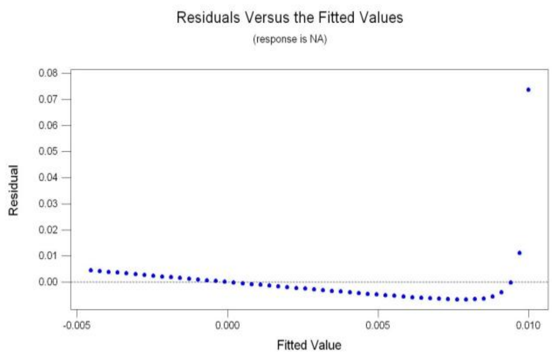


Figure 21: The best accident frequency

D. Reliability Based Validation

Validation and reliability analysis of the model yield the following result. Figure 21 shows accident frequency residual plot from Minitab is shown with good fitness. Figure 22: Shows accident consequence validations, accident consequence good to fit to the method, residual graph of Cumulative Density Function (CDF) profile tracing infinity. In this analysis Frequency is refer to as Fa or Na.



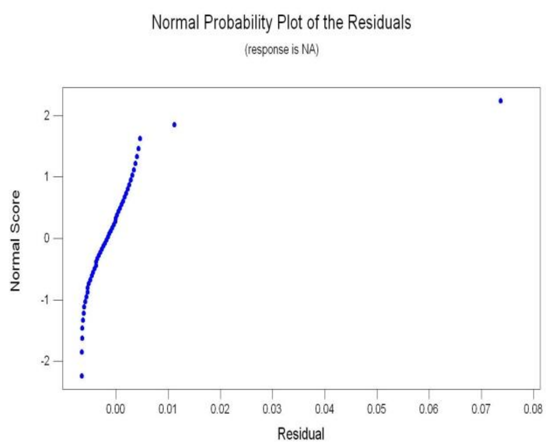
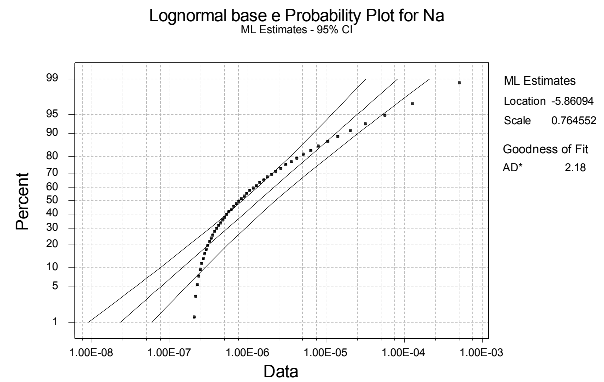


Figure 22a: Accident frequency residual plot, Figure 22b: Accident consequence validation.

Figure 23 shows residual histograms distribution diagram for accident frequency, skewed to low risk area, outlier can be removed

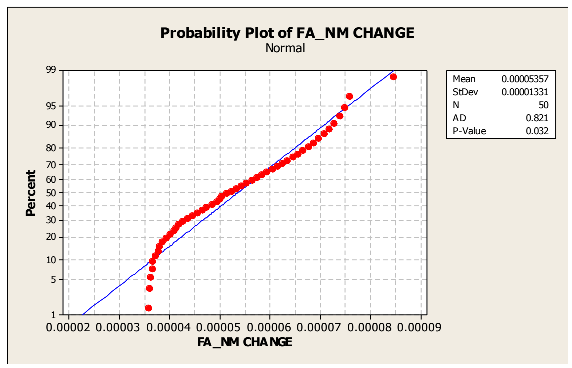
Figure 23: Residual histograms distribution diagram for accident frequency

Figure 23 Shows Log normal plots Accident frequency (Na),



distribution shows a good to fit. Curve Figure 18 b also show a very good curve fit for the model.

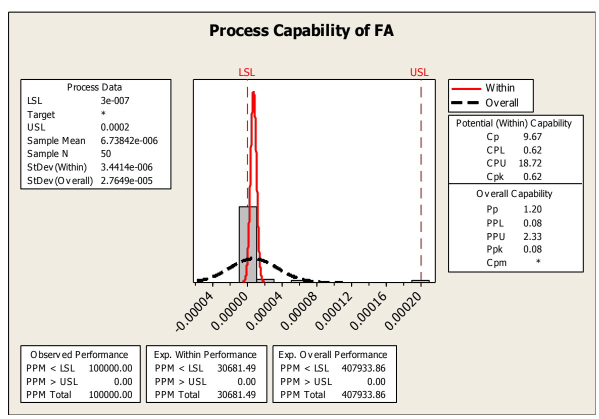
(a)



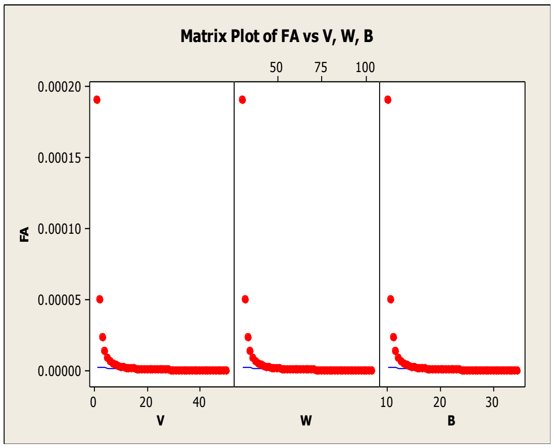
(b)

Figure 23: Log normal plot Accident frequency (Na)

Figure 24 shows process reliability capability, the fitting of the curve revealed the reliability of the frequency model



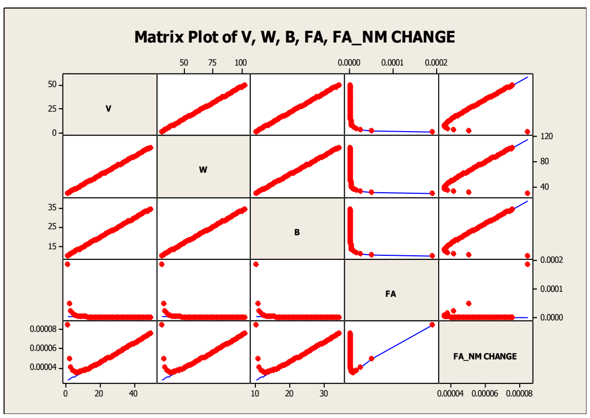
(a)



(b)

Figure 24: Process capability

Figure 20 shows the matrix plot for the model, the safe areas



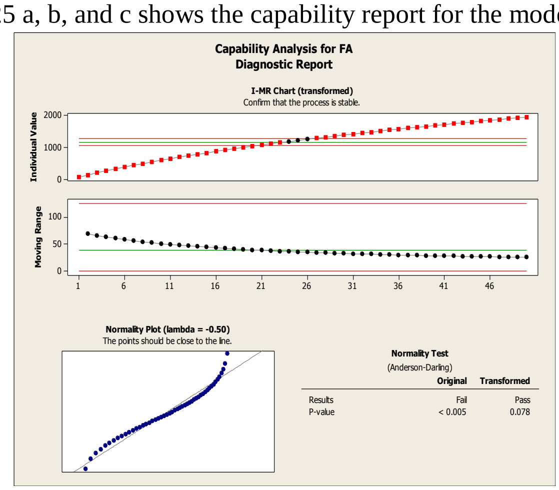
for the variable workability are shown in the matrix plot.

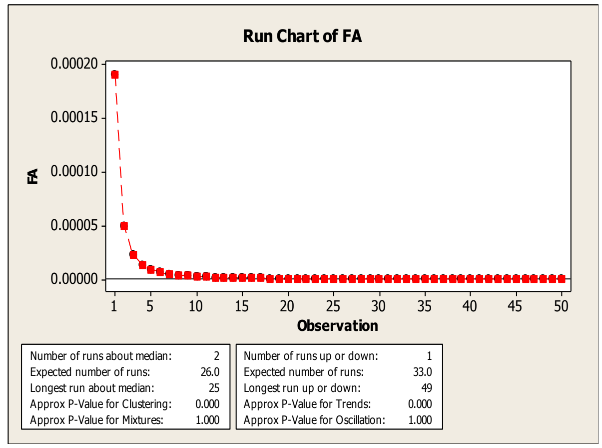
(a)

(b)

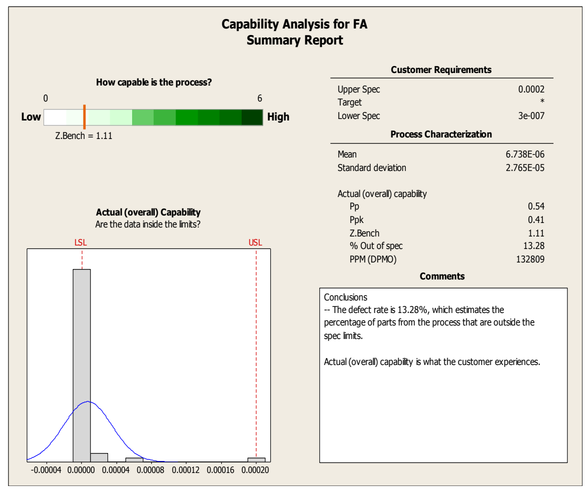
Figure 24: Matrix plot

Figure 25 a, b, and c shows the capability report for the model.





(a)



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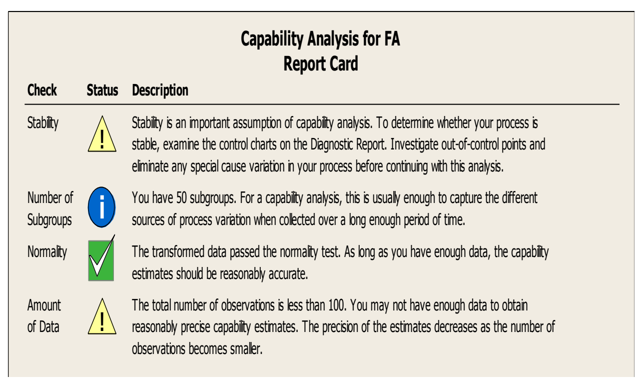

(c)

Figure 25: Log normal plot Accident frequency (Na)

VII. CONCLUSIONS

Hybrid of deterministic, statistical, historical, probabilistic and stochastic method along with channel and vessel profile baseline data has been used to model accident possibility in waterway in order to meet condition for safe transits, and environmental conditions for inland waterway. Factors such as vessel type and size, traffic density, speed and visibility conditions are major risk factor of accidents the probabilistic method represent reliable method to develop models for safety and environmental prevention and collision accident risk aversion who precedence is could be short term (damage) or long term (impact of oil outflow) environmental impact. Accident collision per number of year has been determined for potential decision support for limit definition for number of ship, speed, required width and beam of ship. Variables that affect accident rates have been simulated for necessary limit acceptability purpose for the channel. Accident rate has increased compare to previous year, a situation that required attention for solution. Advantage of implementing of TSS in respect to beam requirement is also presented. Implications of concept of uncertainty can help also on decision support relating to navigational aids and transit regulations for poor visibility conditions as well has employment of improved navigation systems, such as electronic charts, GPS receivers, and VTS, to mitigate causal factors.

APPENDIX

Nm	NUMBER OF MOVEMENT SHIP
V	Speed
T	Draft of the ship
B	Beam of the ship
D	Depth of waterway
W	WIDTH OF FAIRWAY
B1	MEAN BEAM OF MEETING SHIP (m)
B2	BEAM OF SUBJECT SHIP (m)
V1	MEAN SPEED OF MEETING SHIP (KNOT)
V2	SPEED OF SUBJECT SHIP (KNOT)
Theta	Angle
l	Length of ship
Ps	TRAFIC DENSITY OF MEETING SHIP (SHIP/nm^2)
Pi	Probability of Impact
Chead	Head on collision
Cov	Overtaking collision
Ccr	Crossing collision
specific angle	Collision at specific angle
Circuler	Collision at circuler situation

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