Sustainable Periodic Navigation Channel Assessment Initiative for Restricted Inland Waterway

Ab Saman Abd Kader, Oladokun Suleiman

Marine Technology Department,
Universiti Technologi Malaysia,
81300 Skudai, Johor, Malaysia

Abstract: The nature of human activities has remain that one thing will always complement the other. Today the world is moving so fast and but the maritime industry from issue of cybernation of ship to environmental has been quite at low frequency with development. This nitigrity is due to so called conserve nature of the industry and of course, because concerned people are blithely unaware of frequency deviation of the new generation ULCC vessel and in relation with existing channel and port situation, likewise, the international organization, focus too much of their proceedings on vessels in the deep sea, and less on port status or waterway issue. This paper will address environmental, human, and reliability factors affecting our channel in relation to ships operations, channel design, ship design and ship maneuverability in restricted channel, the need for periodic cost benefit risk assessment of restricted channel against new generation of larger class of ships that are coming to the market. The need to generate maritime environment awareness in maritime curriculum through evaluative simulation and assessment of fictitious situation that reflect real life for our channels, deduce actionable alterative options, mitigation measure and recommendation for improving the safety of navigation and protection of the marine environment by enhancing cost effective channel maintenance and controllability of ship in shallow water and restricted water.
Keywords: navigation, risk, safety, environment, channel, ship, maritime, cost, assessment

1.0 Overview

Life of man has always been about pressure - response - action that has lead him to transitions between different technological ages, during this transition he has hardly recognize his inherited and supportive lithosphere, hydrosphere and atmosphere that equally take their natural course as ordained and generate reciprocating response that lead – today both of this reactions has cause imbalance that has resulted to environmental degradation leading to issue of environmental revolt we are seeing today- For years, normal practice of human activities waits for disasters to come before we take care of the environment we live or operate and of course that support our life .It remain our responsibility as human to be serious as time is calling to change the way do things – especially using proactive approach rather than conventional reactive approach necessary for studying , recording, analyzing ,integrating and matching new system with the environment to ensure preparedness and reliability through simulation and adjustment that will minimize calamities and heavy disasters cause by point form degradation that has resulted to unprecedented floods and landslides especially in coastal areas. Multivariable nature of channel maintenance work require studies of various method which we have been exploring, this paper will discuss a holistic methodology approach that will account for proactive assurance and sustainability of channel maintenance work are formulate for one of the nations channel.

2.0 Consequences of System Imbalance

Today and everyday, flood waters is coming and taking over our cities, cut off transport, routes, communication power supplies, have inundated destroyed our homes, crops and livelihoods, affect millions in rural and urban areas. Areas that are especially hard-hit have seen widespread devastation death from heaviest rainfall on record that has forced and forced millions of people from their homes, and neighboring state have seen with unprecedented severe damaged, damage ranging from agriculture and industrial units is also widespread. The Table 1 below shows what disaster has been causing us:

<u>Table 1: Average number of people killed per million inhabitants- By UN Regions 1994 - 2003</u>

Region	hydrometeo	geological	biological	technological
Africa	1.661	0.354	7.436	3.654
Americas	7.613	0.410	0.103	1.318
Asia	2.696	2.412	0.322	1.275
Europe	5.904	0.310	0.054	1.097
Oceania	1.694	7.337	0.937	2.056

The UN investigation has confirmed that almost one million houses are damaged annually by human, economic, social and other similar causes. In recent years, the increasing instances of disasters have heavily affected the socio-economic development across the globe. Below is what disaster has taken out of our pocket.

Source of data: EM-DAT: The OFDA/CRED International Disaster Database. http://www.em-dat.net, UCL - Brussels, Belgium

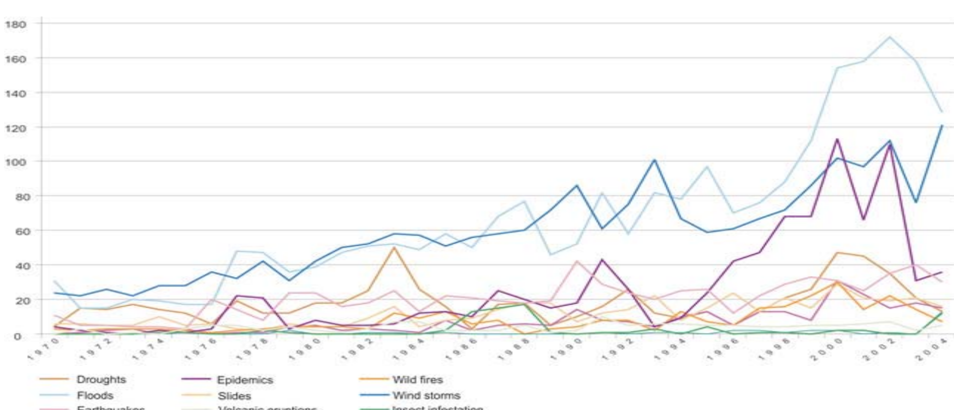


Figure 1: Number of natural disasters by type of triggering hazards1970-2004

These are all consequence of failure and imbalance leading environmental degradation as a result of imbalance of human activities and negligence to our environment –

3.0 Shipping Trend

Ships and shipping remains a very important instrument to mobility, if ships could no longer transit our waterways, we will experience shortages of power, heat and food in days or weeks at the outside. Recent years have seen economic of scale due to improved trade, the significance of these trends is that more, larger ships will continue to use our waterways for the foreseeable future. But there are limits on size of ship that a channel can accommodate, and means of determining when special measures must be imposed on handling ships in order to ensure the continued safe, efficient, and environmentally friendly use of our channel.

This make it incumbent authorities concerned upon regarding our waterways to evaluate and address the risks associated with ships that are plying them and find way and information sharing avenue systems for channel designers, naval architects, ship masters and pilots, and waterway managers that will help develop policy recommendations that will address the way channels are laid out and enlarged and how ships of various types using them should be designed and handled. And of course ways to monitor existing and new ships operating at channel approach in order to guide ship designers understand and review ships, pilot age, channel current design and operational practices on how to make needed improvements.

In shipping, ships coming to the market need to be matched with the port condition , ships are necessary to facilitate trading through marine transportation, and Recent time has proved that there is continuous growth or need for larger and sophisticated ship through increasing shipping activities and this has lead to design and production of sophisticated state of art safety oriented marine vehicle in term of size, speed and structure- albeit, this safety based designed development is out of phase with conditions of navigation channels. To create a balance for safe navigation in restricted water this big ship will ply, we must maintain the channel at a frequency the ship production are growing.

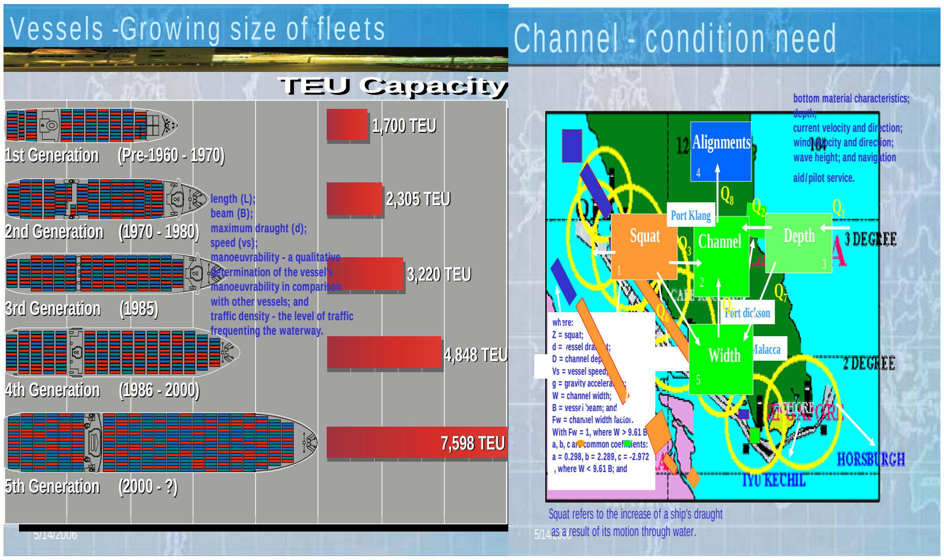


Figure 2 – vessel grow size and condition of channel – source transmarine

Figure 2 shows the growing trends of container vessels and need of channel to match this growth. Recent projection is looking at 18,000 TEU. Which I believe the technological capability is there for such target. As the ship sizes are increasing it is imperative to do periodic examinations of the requirement of the channel in regards to depth, width, squat, and alignment. Channel design and maintenance work fall among the works that require multivariable exercise that need model studies for good outcome. Shoaling remaining unavoidable part of most harbor and navigation channels and one method to preventing shoaling and associated siltation hurdles is using of maintenance dredging at economical frequency.

4.0 Present Coastal Threat in The Strait of Malacca

Analysis drawn from marine departments in figure 3 shows disasters record of the Strait of Malacca – collision and grounding take the highest share of the risk.

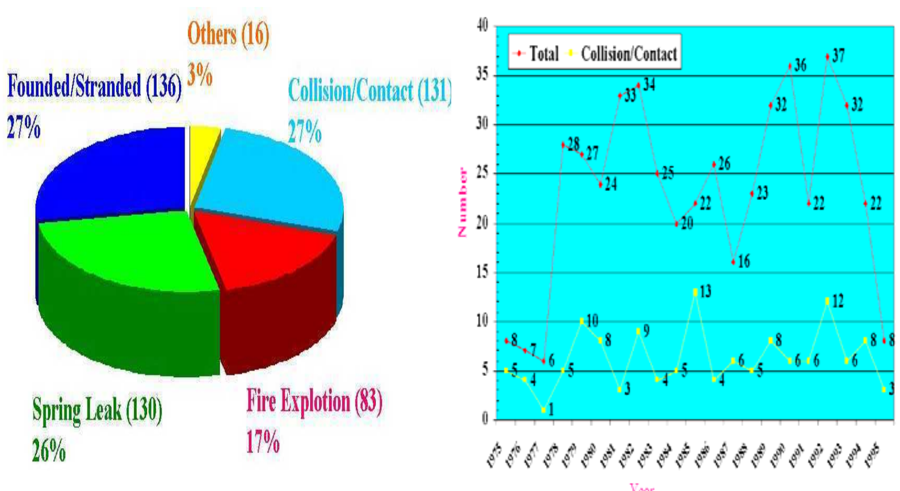


Figure 3: Risk in the Strait of Malacca- source Malaysian Marine Department

Also a risk assessment studies carried out by Norske Veritas for various navigation water ways put present the strait risk situation as follows

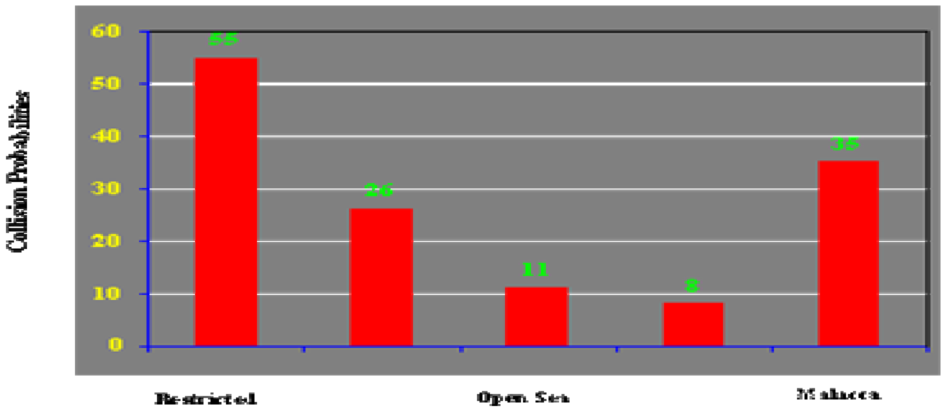
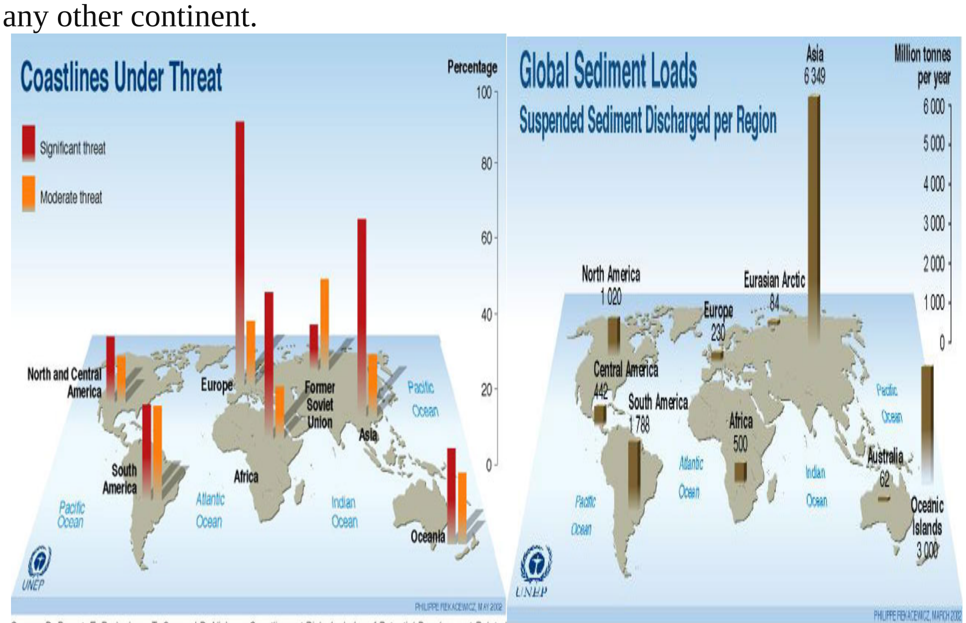


Figure 4: World coast risk area- source DnV

On sustainability, analysis made by the UNEP regarding region under coastal treat concluded that following as shown in fig4, this due to the so due to Asia having a lot of river runs off to the sea than any other continent.



Source: D. Bryant, E. Rodenburg, T. Cox and D. Nielsen, *Coastlines at Risk: An Index of Potential Development-Related Threats to Coastal Ecosystems*, World Resources Institute, Washington DC, 1996.

Source: Peter H. Gleick, *Water in Crisis*, New York Oxford University Press, 1993.

Figure 5: Coastal treats – source UNEP

5.0 Chanel Maintenance Work

Maintenance dredging is the activity of periodically removing material which has been deposited in an area where capital dredging has been undertaken .the frequency of maintenance dredging varies from port to port, however the objective remain to allow ship to enter a leave port at stated draft t without delay and this is what give ensure of efficiency of maintenance dredging. Thus step must be taken to minimize siltation and shoaling .

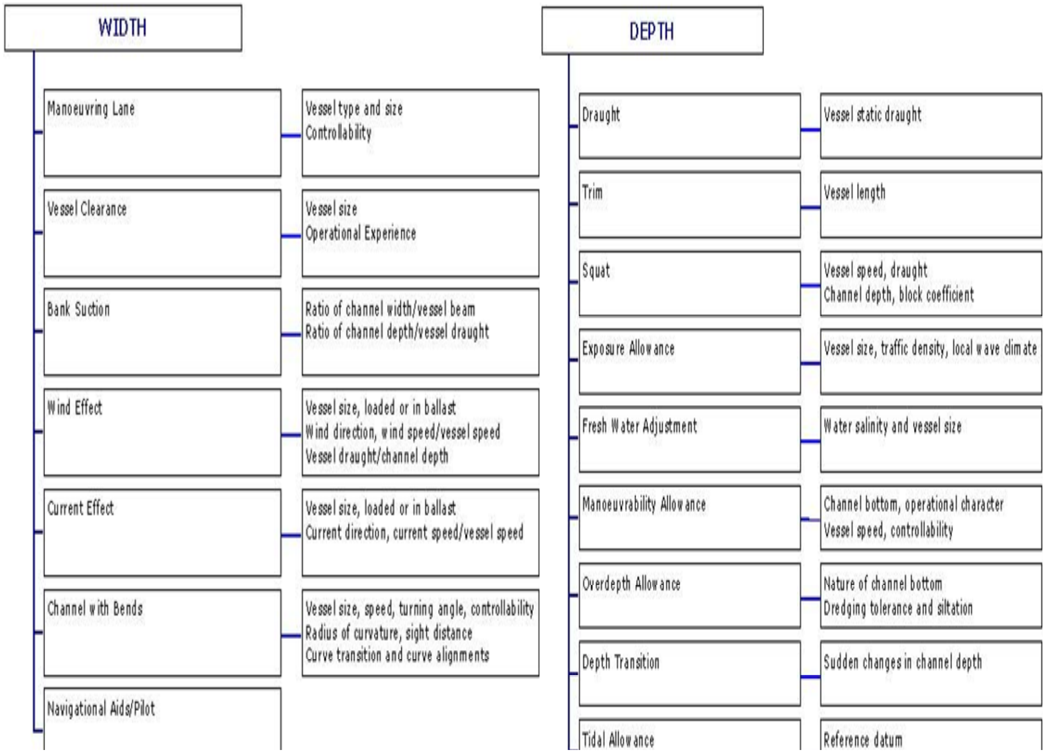
Every human activities on earth is about need and response to need ,and of course mitigation – issue relating to channel and ships is not left behind in this – the Ship is about port -access to port by optimum size ships can be made available through navigable channel where maintenance dredging is needed. Ship production and condition of channel are out of phase. Economic of large scale and demand has begot big ship to emerge within a short period of time after second world war- however less attention has been given to the channel that will continue to accommodate these ships. Large ships typically maneuver with difficulty in confined areas, and channel width is a critical component of deep-draft channels .The requirements for access and protection in harbors and ports often lead to dredged channels and engineered structures, such as jetties and breakwaters.

6.0 Channel Width Characteristics

The main characteristics of a channel may be grouped into the following general categories:

- Channel Layout (i.e., plan view path characteristics such as straight and curved sections)
- Channel Cross-Section (hydrodynamic characteristics such as depth, width, and side-slopes) many factors feed into the determination of the dimensions and specifications of channel characteristics, including:
- Vessel traffic characteristics (e.g., traffic mix and density; length, beam, draft, air draft, etc. of vessels); environmental factors (e.g., tide, wind, waves, currents); and location and characteristics of features such as bridges, and economics, along with many others

Figure 6: Navigation requirement



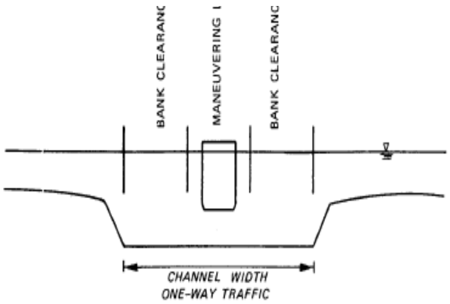
7.0 Channel Depth Characteristics

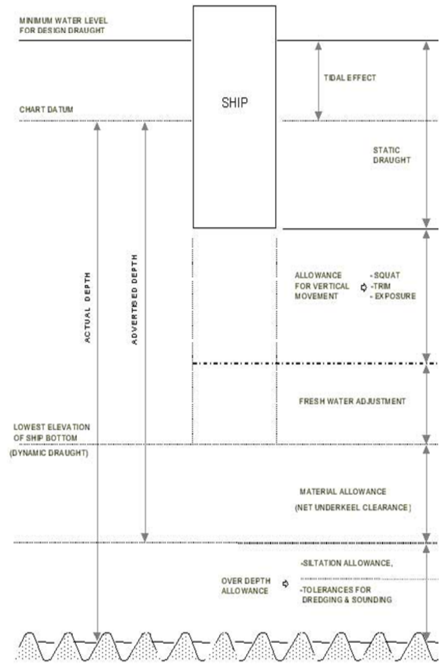
Channel deepening is considered more important by channel designers, economists and mariners alike. PIANC have detailed guidance for determining channel depth based on a number of factors, as illustrated in Fig. 4. Although channel width is treated some what similarly by PIANC, because of conventional definition associated that "depth is for productivity, width is for safety .The significance of this mindset and this trend in channel design is that channel width may potentially be reduced to a point where certain vessels may not even be able to transit a channel based solely on width – similar to the present-day limitation of channel depth. Other more immediate impacts include one-way vs. two-way limitations, as well as reduced vessel speed (and therefore reduced efficiency and perhaps maneuverability) in channels due to increased blockage factors. **T**he following allowance according to water quality of the port

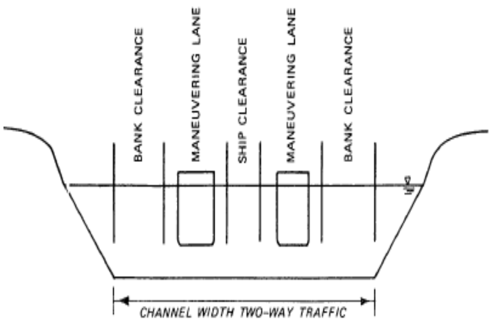
Table 2: Depth allowances

Port location	**allowance**
water	Depth (m)
Blackish water	0.13
Fresh water	0.30

Source: PIANC, 1997







And the following empirical formulae is widely use to determine channel depth and width

$$\Delta W = \frac{0.9144 \phi v_s^2 L^2 F}{R_t C_c S}$$

Actual Waterway Depth = Target Vessel Static Draught + Trim + Squat + Exposure Allowance + Fresh Water Adjustment + Bottom Material Allowance + Over depth Allowance+ Depth Transition

8.0 Design characteristics

Ship - Important characteristics being considered in ship design regarding their controllability in constricted waters are:

- Container ships have large windage that can complicate ship controllability in narrow channels as well as during slow speed maneuvering;
- Direct-drive diesel ships with high installed power to achieve design service speeds can, in some cases, have a minimum bare steerage speed of about 8 knots, quite a high speed in confined waters; and,
- Tankers and dry bulkers are also increasing in size. While the largest tankers, 300,000 dwt VLCCs and 400,000 - 500,000 dwt ULCCs,

Design features, including twin screws and rudders, that are intended to reduce the risk of marine causalities on some new tankers have the additional benefit of improving slow speed maneuverability. However, some new single screw tankers and bulkers being built at minimum cost with low power / tonnage ratios and small rudders do not incorporate these features and pose significant maneuvering challenges in shallow and confined waters. Few of the newest designs are being built at minimum cost. These ships have very low power relative to their dwt as well as rather small rudders.

Channel - Permanent International Association of Navigation Congresses (PIANC) approach to channel design Guide provides the basic assumptions drawn from information sharing in 1978 Symposium that many significant articles addressing issues ranging from technical and maintenance to policy and regulatory and aspects of navigability of "constraint" waterways. Channels are designed to accommodate both the type of vessels and the level of vessel traffic that are forecasted to use a given channel; there are no guarantees that the forecast will accurately predict actual usage. In reality vessels actually transiting the channel are frequently much larger than those for which the channel was designed. At some point, a channel becomes unsafe, unreliable and inefficient for larger and larger vessels. Thus there is no recognized measure or point at which a channel is identifiably "substandard". Channel improvements should ideally keep up with traffic so that a channel never becomes substandard. Previous works in improvement work are done in reactive manner, rather than in a reactive manner.

Shallow / Restricted Water Maneuvering Standard- There is need for a design standard for shallow- and restricted-water maneuvering capability should be established. To ensuring that ships can be controlled when operating in shallow-water, such a standard could also be used to improve the safety of navigation and protection of the marine environment. Thus ships spend 90 – 98percent of their operational lives underway at sea speed in deep water, it is during the mandatory beginning and end of every voyage when the risk of collisions and groundings are highest. Ensuring the ability to maintain complete and positive control of a ship's movement during these segments of a voyage is absolutely vital if that risk is to be reduced. The current practice of not positively addressing shallow-water, slow speed controllability during the design process is not unlike assuming that an airplane will be able to takeoff and land if its inflight controllability is adequate.

Aids to Navigation / Navigation Information- There was some discussion about how navigation systems, both short-range aids, such as buoys and ranges, and systems providing real-time tide and current data methodology and electronic systems for monitoring under keel clearance [15, 16] contribute to ship controllability and remain vital components of the channel that directly contribute to the safe navigation of ships in dredged channels.

9.0 Maintenance Dredging Capacity - Sediments Output and Estimates

Maintenance dredging with objective to reduce channel delay, accept big ship to be done in environmental sustainable manner and optimal efficiency –in maintenance dredging quantifying the loss of depth pave wave for dredging requirement to be determined and this lead to optimal choice of dredger. Generic calculation on data results from analysis of;

i. Vessel and channel requirement
ii. Basic rate output of the dredger
iii. Computation of volume
iv. Cycle time and Number of work day per year
v. Working condition and Environmental discounting

Where:
Output = number of cycle per day load factor x hopper capacity x number of working day
Load factor = volume/ hopper volume
Number of working day per year= 365 days

Iterative process in analyzing the data's will involve dealing with uncertainty and managing the risk and will help to :

i. obtain all concerned involve in formulation of new method
ii. identify the significant and level of each cause, source and impact of the design changes
iii. help deduce the possible corrective actions and preventive measures to minimise the avoidable design changes
iv. help Verified the limitations of the existing methods

On the otherhand, the impact level is characterized into the following categories:

a. Impact to channel during operations (Permanent effect) :
i. Hydraulic (Wave climate in port, Reduction of wave height Navigational condition and safety)
ii. Environmental (Coastline erosion development, Maintenance dredging, salt intrusion into the lagoon)
iii. Fisheries (Aquatic life, Water quality at disposal site)

b. Effect during construction-(temporary):
i. Fisheries
ii. Navigational and port operations
iii. Urban land traffic
iv. Recreation

Prevention is better than cure. In engineering most of the time we design under the condition of uncertainty with regard to material properties, service requirements, and engineering models to name just a few. Navigation, coastal and geotechnical engineers have a very pronounced problem .Past design in human activities has been based on aftermath assessment of calamity where engineers have dealt with the high level of uncertainty by conservatively assigning or specifying much larger capacities than the projected demand. This ratio of capacity to Predicted demand is the classical safety factor approach, which requires significant experience levels to be done right. Conventional project environmental assessment focuses more on economy with pretence that we can't see what surround issue in concern.

.

10.0 Sustainability

Principle 15 of the 1992 UN conference on the Environment & Development in Rio de Janerio:

"In *order to protect the environment, the precautionary approach shall be widely applied by states according to their capabilities. Where there is threat of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost effective measures to prevent environmental degradation"*

In line with UN recommendation to balance environment with economics on development issue with doctrine of sustainability, maritime industry need to adjust to the ways we do things in a world sensitivity characterized by sustainability capacity building, efficiency optimization of development, practice and operations that meets the needs of the present generation without compromising the ability of future generation to meet their need.

10.1 Environmental sustainability

The term “environmental issues” usually implies one of two interpretations:

i. Wind, waves, tides, sediment characteristics and/or other environmental factors involved in channel design and usage, or

ii. Environmental protection in the sense of reducing the negative impact on water quality or aquatic and coastal habitat quality.

The earlier deal is more conventional and there are numerous historical well as recent and predictive datasets. System that provides real-time information about water levels, currents, and other oceanographic and meteorological data from bays and harbors “Now casts” and predictions of these parameters with the use of numerical calculation models are available. In certain locations this information is very important to track because changes to the bathymetry due to dredging or as a resulted in changes in water currents or other oceanographic effects.

The later is more of revolving “environmental issues,” especially difficulty in finding suitable dredged material disposal sites. Access to an easily available, economical disposal site determines economical feasibility of dredging. This an has been a long standing issue, but now because of serious environmental issue and consequence and proof that cost of environmental degradation is enormous required all concerned parties to incorporate positive environmental aspects into channel design instead of just digging deep and hauling the sediment out of the site. Some typical environmentally beneficial uses of dredged material include;

i. Watch out for reef and coastal species
ii. wetland creations or improvements
iii. Beach fills and/or shore protection.
iv. Coal combustion by-products as cultch material
v. Recycled of seds. for roadways, golf car paths, and building foundations
vi. Developed on-site system to treat contaminated marine sediments

10.2 Economic sustainability

The economic optimization of a waterway requires study of several alignments and channel dimensions (width and depth) that are acceptable for safe and efficient navigation. Costs are developed for the alignment and dimension for each alternative. Benefits are determined by transportation savings with consideration of vessel trip time and tonnage, delays for tides, weather conditions and the effects of reduced depths in waterways that have rapid shoaling tendencies. For larger traffic in limited-depth waterways, reconciliation between safety and efficiency becomes a complex challenge, both to the regulatory and operational agencies such as;

i. For the regulatory agencies, it is extremely important to ensure that safety is not compromised for the sake of efficiency.
ii. For the operational agencies, it is equally important that efficiency is not compromised in order to optimize safety.

The optimum design of a waterway requires studies of the estimated costs and benefits of various plans and alternatives considering safety, efficiency and environmental impact. These studies can be used to determine the most economical and functional channel alignment and design considering initial dredging, maintenance and replacement costs for different design levels

11.0 Risk Assessment Analysis

Risk Benefit-Cost Analysis (RBCA) is a tool for organizing information on the relative value of alternative public investments like environmental restoration projects. When the value of all significant benefits and costs can be expressed in monetary terms, the net value (benefits minus costs) of the alternatives under consideration can be computed and used to identify the alternative that yields the greatest increase in public welfare. However, since environmental goods and services are not commonly bought or sold in the marketplace, it can be difficult to express the outputs of an environmental restoration project in monetary terms. However complicated factors associated with cost quatification exercise are;

i. A lot of money must be spent up front to deepen a harbor, but the benefits are realized little by little over time. The distributional effects of publicly funded projects must be considered from the standpoints of equity and justice.
ii. Harbor deepening can result in significant externalities–benefits or costs that are not directly generated by the investment under consideration, but that are the indirect result of that investment.
iii. Not all the costs of harbor deepening can easily be monetized. There are very real costs, for example, associated with the resuspension of contaminated sediments, the use of upland sites or ocean bottom for the disposal of materials, and the loss of marine life, such as loggerhead turtles, during the dredging process

11.1 <u>Distinguish Hazard & Risk</u>

Hazard: Anything that can cause harm (e.g. chemicals, electricity, natural disasters)

Severity may be measured by;

i. No. of people affected
ii. Monetary loss
iii. Equipment downtime
iv. Area affected
v. Nature of credible accident

Risk assessment is a process that evaluates both the SEVERITY and PROBABILITY of adverse consequence (Hazard) of the project.. Systematic process to quantitatively measure perceived risks/values of waterways using input from waterway users/experts. Hence;

RISK = Hazard x Exposure (an estimate on probability that certain toxicity will be realized)

12.0 Dealing With Uncertainty

Uncertainty will always be part of our activities because of limitation of knowledge of unseen in real world settings issue associated with uncertainty are normally;

i. Influences on recovery process
ii. Test of new advancements
iii. Influence on policy
iv. Address system changes over time
v. Services & resources\

12.1 Benefits and harms benefits

Risk management is the evaluation of alternative risk reduction measures and the implementation of those that appear cost effective .where Zero discharge = zero risk, but the challenge is to bring the risk to acceptable level and at the same time, derive the max. Benefit.

Uncertainty because of the highly variable nature of elements and properties involved with the situation

i. Simulate extreme condition and model – using combination mmathematical modeling and stochastic techniques while considering all factor in holistic manner .
ii. Risk areas and assessment – taking all practical using historical data's and statistics that include all factors - Public health (people > other species)
iii. Mitigation to risk assessment and risk areas - This involves making permanent changes to minimize effect of a disaster- Immediacy: (Immediate threat>delayed threats)
iv. Prefer and no option choice - As prophesied my Newton- time travel in space, no matter what one thing must compensate for the other.
v. Panel of expert -Reach out to those who are capable to extend hand and do the right thing at the risk area- Uncertainty (More certain > less certain)
vi. Community participation - Educate and all concern about the going and lastly place firm implementation and monitoring procedure.- Adaptability (Treatable > untreatable)
vii. Emergency response – provide monitoring and information facilities and make sure necessary information is appropriately transmitted and received to all concerned-Reversibility (Irreversible threat more than reversible threat)

13.0 Conclusion

Critical activities involved in port projects like entrance channel design, oil spillage, break touches, navigations condition, oil spillage, fisheries, aquatic life, sediment and disposal need go through intense studies and review on justification of containment measure recommended for better protection against wave, improvement of navigational safety conditions. But little is not done on making policies to for periodic overhauling or assessment nor do such do critical test or simulation of extreme flooding hat visit hearth like tsunami. various environment institution have various methodology and limitation they follow to simulate or determine risk , integrating them or using good faculty of judgment to borrow them in other situation could be good thing to be ahead of destructive disaster. In shipping IMO has standard rules and limitation assigned for disaster and of vessels and channel. But nonetheless, there is no standard rules put in place for periodic simulation and assessment.

The marine department mission is to provide safe, reliable, efficient, and environmentally sustainable waterborne transportation systems (channels, harbors, & waterways) for movement of commerce, national security needs, and recreation." However, there seem to become fundamental difficulties in achieving this mission. Most notably is that there are no recognized standards for safety, reliability, efficiency or environmental sustainability relative to navigation channel promulgated by PIANC. Risk and uncertainty analysis of channel design and usage is desperately needed – to incorporate vessel transit data, accident data, as well as other factors into an assessment of channel safety, reliability and efficiency. However, it is a challenge to even define "risk" in terms of channel design due to the varying independent, dependent, and coupled factors involved. The role of simulation in the design process is valuable and significant, but simulation technology needs to be supplemented with other tools for assessing total risk and uncertainty. Perhaps the most important issue identified in the discussions is that channel design is often done in a purely reactive manner.

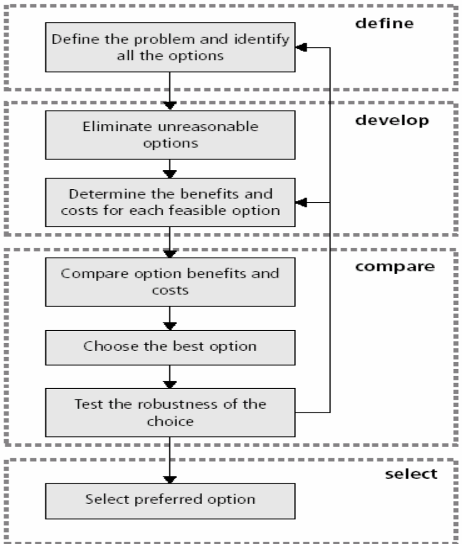
There is an acute need for a proactive process to look at improving channels to meet larger vessels, as well as to meet the significant changes in the nature of maritime shipping. Future vessel designs and design trends could be regularly tracked and incorporated into planning processes.. However, in most places people are completely unaware of the existence of maritime shipping industry and cannot even begin to realize the impact it has on our daily lives and our quality of life.

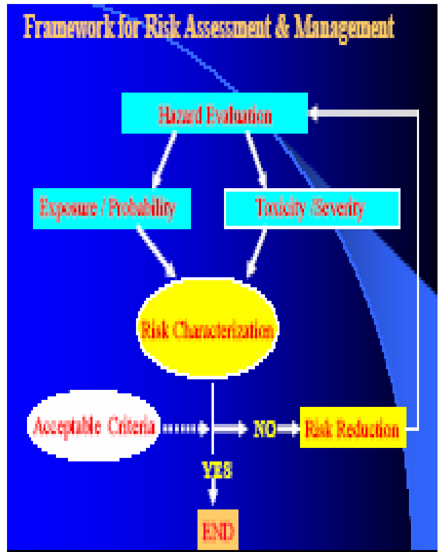
The way things started forming and how the world started closing together; even with the aggressive harmonization with the environment is obviously integrating all professional together nowadays. Shipping industries are not left out in this need to maintain balance with the environment is obviously calling for work on vessel design, *Channel design and Vessel Maneuverability and professional* - channel designers, naval architects, pilots, and ship operators to review and share design approaches and standards that affect safety of operations and the environment. This will nonetheless led to development of policy, recommendations that can be implemented both in the way channels are laid out and enlarged and how ships of various types using them should be designed and handle with Resulting recommendations based on the discussions promises to improve overall safety of ship operations in restricted waterways.

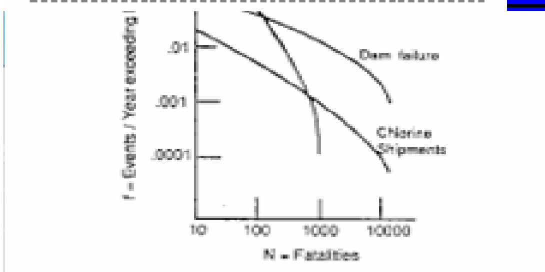
14.0 REFERENCES

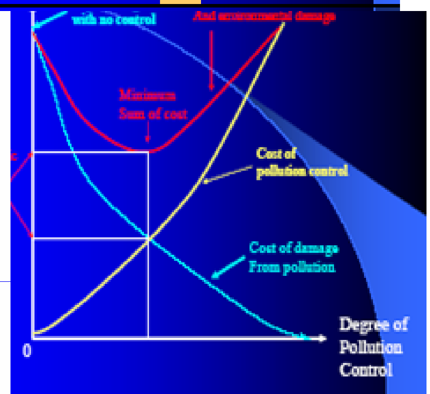
1) Bian Hayman, Mario Dogkgliani,,Ivar, Kevale,Anik Margerholm Fet, 2000.Technologies for reduced environemenatal impact of ships-shipbuilding, maintenance and dismantling,Proc. ENSUS`2000, UK, pp2-24
2) Watson, David G. M. Practical Ship Design. NewYork: Elsevier, 1998.
3) Landsburg, A.C., J.C. Card, C.L. Crane, P.R. A lman,W.R. Bertsche, J.W. Boyleston, H. Eda, V.F.McCallum, I.R. Miller, and A. Taplin, "Design and Verification for Adequate Ship Maneuverability," NAME *Transactions*, Vol. 91, 1983.
4) GESAMP (1993) Impact of oil and related chemicals and wastes on marine environment, GEAMP reports and studies No50 joint group of expert of marine pollution. Available at: http://www.gesamp.imo.org/no65/
5) IMO (2000) marine environmental protection committee 44th session available at: http: www.imo.org/meeting/44.html
6) PIANC. 1997b. .Guidelines for the Design of Armoured Slopes Under Open Piled Quay Walls, Supplement to Bulletin No. 96, Permanent International Association of Navigation Congresses, Brussels, Belgium.

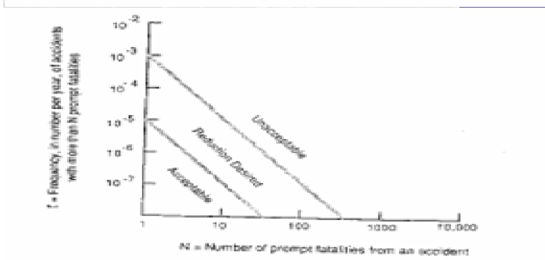
Appendix: Framework for Risk Cost Benefit Assessment

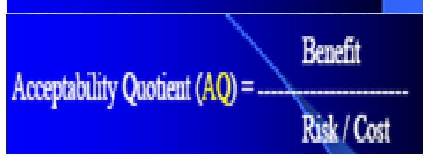

define
Define the problem and identify all the options
develop
Eliminate unreasonable options
Determine the benefits and costs for each feasible option
compare
Compare option benefits and costs
Choose the best option
Test the robustness of the choice
select
Select preferred option


Framework for Risk Assessment & Management
Hazard Evaluation
Exposure / Probability
Toxicity /Severity
Risk Characterization
Acceptable Criteria
NO
Risk Reduction
YES
END


f = Events / Year exceeding
.01
.001
.0001
Dam failure
Chlorine Shipments
10
100
1000
10000
N = Fatalities


with no control
And environmental damage
Minimum Sum of cost
Cost of pollution control
Cost of damage From pollution
0
Degree of Pollution Control


f = Frequency, in number per year, of accidents with more than N prompt fatalities
Unacceptable
Reduction Desired
Acceptable
N = Number of prompt fatalities from an accident


Acceptability Quotient (AQ) =
Benefit
Risk / Cost