Ensuring the Safe and Efficient Movement of Ships in Channels

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Abstract

The safety and efficiency of the movement of ships in dredged channels is significantly influenced by the design and construction of the channel as well as by the extent to which the controllability of ocean going ships is considered during the ship design process. The channel design process requires consideration of both the physical and maneuvering characteristics of a "typical" or "design" ship. Although this implies that the channel should be capable of safely and efficiently accommodating the design ship, it does not mean that it can safely and efficiently accommodate all ships either in service or those that may enter service in the future. Similarly, the ship design process requires consideration of the ship's maneuverability. However, the current guidelines for ship maneuverability consider only deep water performance, and typically do not address performance in shallow or restricted water. Therefore, these guidelines do not necessarily ensure that a ship's maneuverability is adequate to safely and efficiently move through a channel. Finally, responsibility for ensuring the safe and efficient movement of a given ship in a particular channel is shared by the ship's master, the pilot aboard the vessel and regulatory agencies responsible for waterway management.

The International Workshop on Channel Design and Vessel Maneuverability was held 3-4 May 2001 in Norfolk, Virginia, USA. The workshop provided a forum for experts from various involved disciplines to discuss, debate and better understand the relationship between channel design and ship design, as well as navigation and waterway management issues that result when ships and channels meet. This paper discusses many of the changes that may be necessary to improve the safety and efficiency of vessel movement in restricted channels. This paper should be of interest to all concerned with the safe and efficient movement of ships in channels.

Introduction

For many nations throughout the world, the systems of waterways and harbors are some of the most important elements of the nations' commercial transportation and national defense systems. As international trade increases globally, the contribution of maritime trade becomes an increasingly larger percentage of the gross domestic product (GDP) of many nations. Coastal ports and harbors also often serve as vital logistical transportation centers to deploy and support military troops.

These statements are particularly true for the United States, where total annual waterborne commerce in 2000 was approximately 2.3 billion tons, with slightly more than half of the cargo (by weight) attributed to imports and exports, while the remainder of the cargo was shipped as domestic internal (waterways), coastwise, lakewise, and intraport waterborne commerce (USACE, 2001). Perhaps more importantly, international trade is approximately one-fifth of our GDP, with more than 95% of the global trade being transported via ship and traveling through our waterways and harbors into our ports. Both coastal and inland waterways in the U.S. have been essential to the operations of our military and are vitally important to the movement of military equipment. Therefore, keeping waterways, ports and harbors safe, efficient and reliable is essential to national strength and stability – economic as well as otherwise.

Historically, ports have continually faced the challenge of handling larger ships. While the overall challenges of channel design, ship design and waterway management are not new, the challenges are changing and are becoming perhaps more acute in view of the current global climate. In addition, it is well-known that the design process for channels is – and has always been – independent of the design process for ships, and the evolving trends in the two sectors have been contributing to increasing difficulties in waterway management.

International Workshop on Channel Design and Vessel Maneuverability

Often, vessel dimensions and vessel traffic on a waterway exceed the original design vessel conditions for the channel. Concerned mariners and pilots skillfully handle these ever-larger vessels in channels whose dimensions are either not increasing proportionally or not increasing at all. However, there are limits to the physical size of a ship that a channel can accommodate. Prior to extreme physical limitations such as ship draft exceeding channel depth or ship beam exceeding channel width, as ship dimensions increase, risk increases, and safety, efficiency and reliability of the waterway all decrease. It is incumbent on the designers, users and managers of waterways to evaluate and address the risks associated with bringing larger and larger vessels into a waterway.

These issues were the subject of the "International Workshop on Channel Design and Vessel Maneuverability" held in Norfolk, Virginia on May 3-4, 2001 as described by Gray, et. al. (2002). The workshop was intended to provide an opportunity for channel designers, naval architects, ship masters and pilots, and waterway managers from the US, Europe, and Asia to share information and address all aspects of these issues. The goal was to develop policy recommendations addressing how channels are designed and improved and how ships of various types using them should be designed and handled. For example, the International Maritime Organization (IMO) has for years provided guidance criteria for the maneuverability of ships operating at sea-speed in open water. But these are only guidelines with which many ships do not comply. And since the guidelines are for deep water, they likely will not ensure that a ship is maneuverable at slow speed in a restricted waterway. All agreed something better is needed, and soon.

The pilots, mariners, naval architects, and channel designers at the workshop presented the varied and complex perspectives of many concerns related to waterways and proposed some fresh and practical approaches for addressing these complex issues. While many of the specific issues had a distinctive U.S. focus, the international participants noted and reinforced that the issues were unquestionably global in nature. This paper loosely draws from, elaborates and/or expands upon some of the findings from the workshop.

How Channel Design and Ship Design Combine to Create Challenges

Dynamic changes are occurring in the international shipping industry. Figure 1 shows ship types organized by general commodity type transported. Containerships, a subset of general

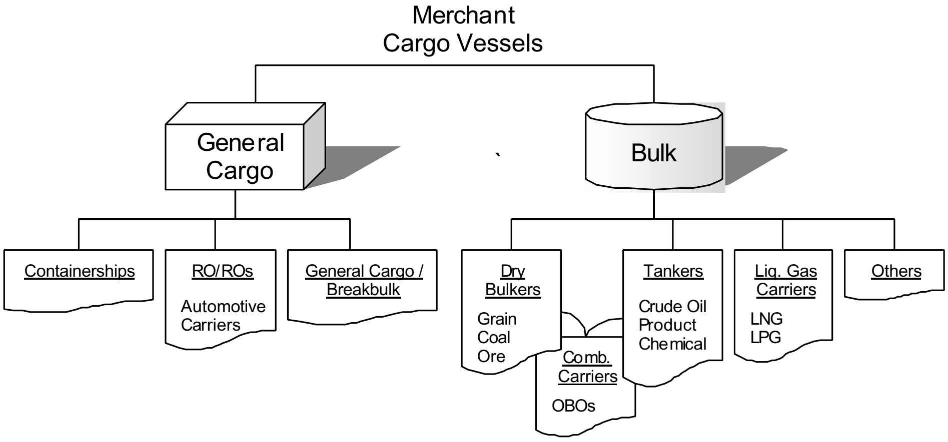

Figure 1: Cargo vessel types

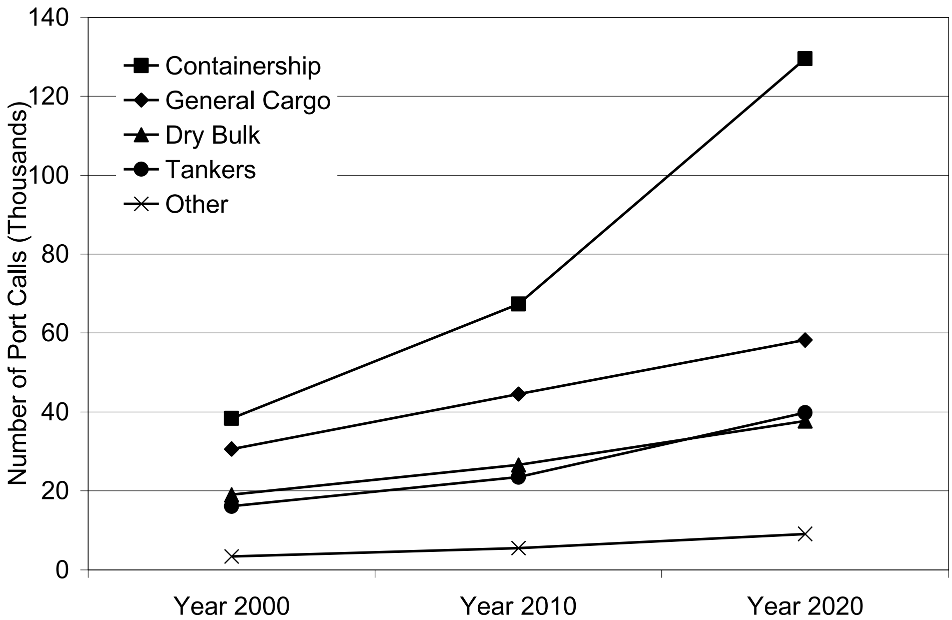

Figure 2: Projected vessel calls on U.S. ports

cargo ships, are of the youngest of the vessel types shown, and are the fastest growing vessel type in international trade, as discussed by Waters, et. al. (2000).

Projected U.S. port calls by deep-draft vessels through 2020 are shown in Figure 2; note that within two decades, the number of containership calls is expected to exceed the combined number of calls of all other vessel types. Containerships typically carry the highest valued cargo per ton (such as manufactured goods) as compared to bulk vessels, and are therefore more likely to have a significant economic influence on most navigation projects. Some particularly notable physical characteristics of containerships as compared to most other vessel types include very high air draft and windage areas. These two characteristics make containerships more sensitive to above water issues, such as bridge clearance difficulties and significant wind force effects when traversing waterways. These issues are only the beginning of a number of elements of waterway design and management that extend well beyond the dredged underwater features of a channel.

Containership liner operators are combining their operations at sea and on land, by merging or forming global alliances. These changes have resulted in the construction of larger containerships, dubbed "mega-containerships" and the liner operators are beginning to consolidate around "hub" ports. The handling of these megaships is quite complex – they require sophisticated and efficient port and terminal facilities (e.g., larger cranes, berths, storage yards) with excellent landside intermodal connections. However, even getting a megaship to a port terminal is a challenge. Most U.S. waterways are currently unable to handle these ships based on nominal dimensions shown in Table 1. At many ports, the economics of these new vessels may result in fewer port calls or no port calls from megaships.

Table 1: Container ship trends
[Adapted from Henson and deJong (2001)]

TEU	DWT	Length (m)	Beam (m)	Depth (m)	Draft (m)	Speed (kts)
2,000		242				32.0
6,600	104,750	347	42.8	24.1	14.50	24.0
6,690	88,669	300	42.8	24.4	14.00	24.5
7,400						
7,500	100,000	320	42.8	24.5	14.50	
8,850		348	45.3	27.0	14.00	25.0
9,000						
11,989	157,935	400	50.0	30.0	17.04	25.0
12,000		380	54.5		14.00	
12,500	123,125	381	57.0		14.70	25.0
18,154	242,800	400	60.0	35.0	21.00	25.0

In dealing with forecasted commerce demands and changes such as these presented here, both the channel design and the ship design communities must react. The two communities do not react in the same way, nor even at the same time, which is the beginning of the real difficulties. Channel design and improvements are usually performed in a reactive manner; that is, channels will not be dredged deeper or larger unless the requirement (e.g., the larger vessel or increased traffic) already exists. In contrast, the ship designer – by direction of the shipping company – usually steps forward and designs a vessel that has a larger cargo-carrying capacity in order to benefit from economies of scale. Ship designers may or may not limit particular vessel dimensions (e.g., draft) because of known limiting waterway dimensions. There have been instances in the U.S., for example, where a large vessel has been designed and constructed with the expectation that one or more U.S. ports will initiate and expedite channel improvement projects in order to be able to accommodate the vessel. The key problem with this method is that it takes approximately 20 years or more from the initiation of a navigation project to the completion of the project; during that time, the vessel's service life is more than two-thirds expired and the design process for the next generation of ships is just beginning.

By the very nature of the difference in timing of the design of the channel and the design of the ship, the processes are rather independent and isolated from one another. The process for each is extremely complex and involved, yet there is little feedback between the two disciplines, and clear opportunities exist to improve and enhance both processes by incorporating enhanced technical communication as well as feedback loops. The design process for each discipline already incorporates a myriad of governmental and commercial agencies or entities, some with shared interests in the project, some with competing interests

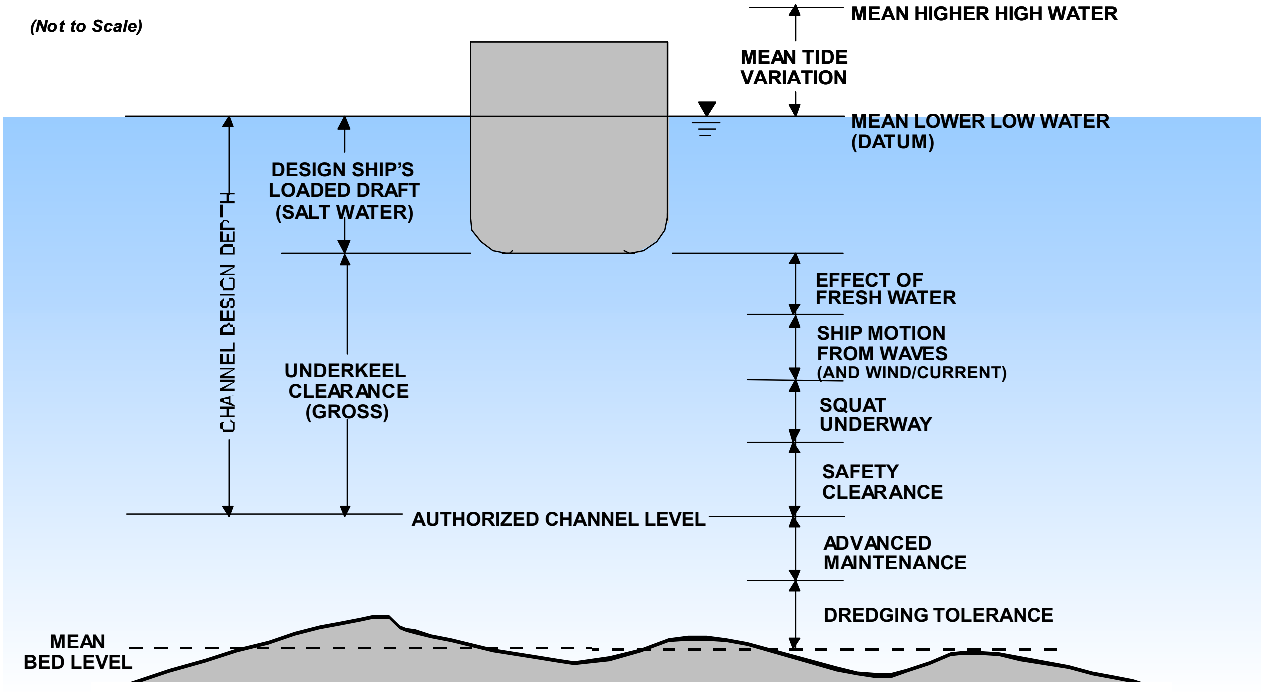

Figure 3: Schematic of factors included in determination of channel depth [After USACE (1983)]

in the project. The tradeoffs in all cases are ultimately economically driven, and a symbiotic relationship between the channels and vessels can only enhance the economic and other benefits of the waterway.

Specific Channel Design Issues

It is well recognized that the U.S. Army Corps of Engineers (USACE) is the principal organization in the U.S. responsible for navigation channel design guidance, maintenance, and operations, and PIANC is the recognized analogous authority internationally. In practice, it is common for both U.S. and non-U.S. channel designers to consult guidance published by both USACE and PIANC. As discussed by Kriebel, et. al. (2000), while the prescribed procedure for channel design is similar based on the guidance documents from the two organizations, much of the details of the analytical calculations vary significantly. In the end, however, the differences between the resulting dimensions are usually modest.

The channel design process usually begins with a reconnaissance phase in which current and predicted commerce requirements, design vessels, as well as physical, environmental and economic data are investigated. Based on positive results discovered during the reconnaissance phase, the project proceeds through a feasibility study, where variations of channel designs are identified and evaluated, then to detailed design, where final plans and specifications are developed. Both organizations recommend incorporation of vessel simulation (usually implying computer simulation) in channel design to "check" the paper design. The capability to utilize simulation as a design tool is still not yet mature. Very little full-scale data is available to validate simulation results, and usually the number of simulation runs/scenarios is small and limited. The temporal and economic expense of simulation is presently rather significant, but should lessen as simulation technology develops.
Perhaps the most overlooked issues during channel design are those associated with vessel characteristics. Usually, only vessel length, beam, draft, and deadweight tonnage (DWT) are

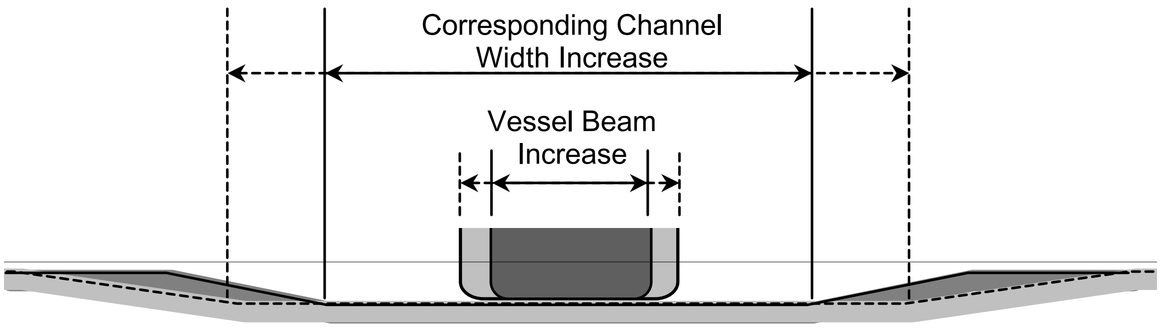

Figure 4: Schematic of vessel in one-way channel illustrating implication of larger vessel beam on corresponding channel design width

examined, and often, only draft and DWT are used in the early stages of design. It is apparent that vessel draft, which ultimately drives channel depth, is nearly unanimously viewed as the most critical parameter in channel design. From the vessel's static draft, allowances for a variety of other phenomena are estimated to determine the ultimate required channel depth to accommodate a vessel with a particular draft as shown schematically in Figure 3.

Other vessel dimensions and parameters that contribute to the vessel's maneuverability characteristics are usually not addressed until much later in the design process (i.e., simulation), if at all. Future vessel characteristics are also extremely difficult or impossible to predict and incorporate into a study. Usually shipbuilding order logs cover at most five out-years, yet a channel improvement project will not be completed until twenty years have elapsed. This time variance introduces potentially large fleet composition differences between the forecasted fleet when a project is initiated and the actual fleet at the project's completion. A means of updating fleet forecasts throughout the life of the channel design should be developed and implemented whenever possible so that the channel design is not obsolete before it is constructed.

More tools to track and predict trends in vessel parameters need to be developed, and should include maneuverability measures as well as strict linear and volumetric measures. For example, a recent study by Waters, et. al. (2000) discovered that vessel beam dimensions are increasing faster than any other dimension. Additionally, there is evidence that vessel block coefficients are increasing. Without respective channel modification response, the combination of just these two vessel physical trends may result in vessels that are significantly more difficult to navigate through restricted waters.

Figure 4 shows a cross-sectional view of a vessel in a dredged fairway designed for one-way traffic (channel width shown is approximately three times vessel beam). The figure is a simplified, proportionately-scaled representation of a vessel with a 45 m beam and 14 m draft in 15.5 m depth of water. Note that a typical 1.5 m underkeel clearance is barely noticeable when compared to the other dimensions. Shown also on the figure is vessel with a larger beam and the associated implication on design channel width. If channel width is not increased proportionately, the vessel blockage factor (submerged cross-sectional area of the hull divided by submerged cross-sectional area of the channel) will increase, resulting in increased squat and bank effects, as well as other maneuvering problems.

Specific Ship Design Issues

In order to ensure safe and efficient movement of ships through channels, the vessel must be reasonably easily controlled when entering, operating within and exiting the channel. Factors considered particularly important for general ship controllability include:

- Length/beam (L/B) ratio
- Rudder size
- Power/tonnage ratio
- Minimum bare steerage speed

Length/beam ratios are decreasing as naval architects increase ships' beams as a means of multiplying cargo capacity without increasing draft. Increasing beam reduces a vessel's directional stability making it easier to initiate a turn; however, directional instability also makes it harder to stop, or check, a turn once started. Shallow or restricted water compounds this effect.

The rudder is a ship's most important control surface and is usually the primary (and often the solitary) means of maneuvering a vessel under its own power. In general, the performance of a rudder is directly proportional to the rudder area and to the square of the speed of the water passing over the rudder. Although rudder size and velocity are important, there are other factors influencing rudder effectiveness that must be considered when evaluating whether a particular rudder will provide adequate controllability at slow speed in shallow water. These include rudder type, e.g., horn or spade, the foil shape, the rudder's angular rate of turn, and shape of the hull just forward of the rudder [Gillmer and Johnson (1982)]. Additional factors that must be considered include the number of rudders and the location of the rudder(s) relative to the propeller(s). Another rudder-related issue of concern is that a vessel typically requires much more rudder force to correct a turn than to initiate a turn, especially in restricted water. Often when maneuvering through a channel, many vessels do not have nearly as much difficulty turning as they have stopping a turn.

Rudders of many ships are becoming smaller relative to increases in length (L), breadth (B) and draft (T). It has been noted that while the trend toward smaller rudders relative to overall ship size may not adversely impact controllability at sea speed in deep water, it does have an adverse impact on controllability at slower speeds in narrow channels and in shallow water. PIANC (1997) includes data illustrating the dependence of turn radius on depth-to-draft ratio for a particular vessel. It is immediately apparent that turn radius increases significantly with decreasing underkeel clearance.

In 1972, Det Norske Veritas' (DNV) rules included a formula for calculating rudder area, A_R, that was based on L, B, and T. The formula was:

$$A_R = \frac{TL}{100}\left[1 + 25\left(\frac{B}{L}\right)^2\right]$$

The DNV (2000) rules have subsequently been refined to account for vessel block coefficient, C_B:

$$A_R = \frac{TL}{100}\left[1 + 50{C_B}^2\left(\frac{B}{L}\right)^2\right]$$

The fact that the refined formula accounts for block coefficient can be inferred as an acknowledgement that for a given L, T and B, higher displacement vessels require a larger rudder. While the DNV formula does suggest rudder size based on various vessel parameters, it is an optimized rudder area for controllability at sea speed in deep water as evidenced by the following statement included in the guidance: “For ships which frequently manoeuver in harbours, canals or other narrow waters, the rudder area determined by the formula should be increased.” [DNV (2000)]

Vessel masters and pilots have also expressed concern that as power/tonnage ratios decrease, some ships are becoming increasingly difficult to control in shallow or confined waters at slow speeds. This is because underpowered ships lack sufficient reserve power to provide a reasonable “kick” when the engine is ordered half or full ahead to increase water flow over the rudder during a turn.

Another propulsion factor that influences ship controllability at low speeds is the type of propulsion system that is installed. Of concern is the difference between bare steerage speeds (the speed at which the rudder is effective) and “dead slow ahead” speeds (the minimum speed a vessel will make through still water with its propulsion continuously engaged). Ideally, a vessel’s dead slow ahead speed is less than its bare steerage speed. However, dead slow ahead speeds in excess of 5 – 6, even 8 knots are becoming more common; this is particularly of concern for container ships with high design service speeds. A reason for the higher dead slow ahead speeds is that direct drive slow-speed diesels have a limited RPM range and require propellers with sufficient pitch to achieve the designed service speed. In other words, at the slowest engine speed possible, the vessel is moving significantly above the bare steerage speed. While the vessel theoretically has steering capability, the speed may be too high for prudent operation in particular scenarios. It may be possible to slow such a vessel down to maintain bare steerage speed by repeatedly starting and stopping the engine; however, this technique is avoided unless absolutely necessary since it increases the risk of a propulsion failure insofar as the available start air may be depleted more quickly than it can be replenished.

Also of concern is that there may be a significant difference between bare steerage speed and the speed at which an astern bell can be ordered. For example, if a ship’s dead slow ahead speed is 8 knots, but an astern bell cannot be ordered unless the vessel’s speed is less than 3 knots, the vessel would need to “coast” or have tugs slow the vessel before changing engine thrust direction. This highlights an additional advantage of electric drive, controllable pitch propellers, and reduction gear for ship controllability – these propulsion systems permit the direction of thrust to be reversed more quickly than with a direct drive diesel and without using any start air.

Ships operating on the navigable waters of the United States are currently required by 33 C.F.R.§164.35(g) to have maneuvering information posted on the bridge. This information, which is based on tests conducted in deep-water, includes a turning circle diagram as well as tables showing time and distance to stop the vessel from full- and half-speed. Although this information is useful, it does not communicate the maneuverability of a ship insofar as it does not provide a means of directly comparing the maneuvering characteristics of a given ship relative to an established standard. This is the same for the maneuvering information that IMO Resolution A.601(15) recommends should be provided aboard ship.

Pilots currently fill this information void by informally comparing the maneuverability of different ships amongst themselves. While these informal comparisons provide pilots with information that they need, it is ex post facto. In other words, it is information that can only be gained by actually handling the ship in a restricted channel and potentially hazarding the safety of navigation or the marine environment. It should also be noted that this information is generally not shared between pilot associations. Since this information is generally based on a subjective comparison, its usefulness to organizations such as the U.S. Coast Guard (USCG) for making operational decisions or the USACE for evaluating a channel design is limited. Being able to communicate the maneuverability of a ship relative to an objective standard would make it possible for masters, pilots, and the USCG to make better decisions regarding a ship's movement and imposition of operational controls. It may also contribute to improving the channel design process.

Risk and Uncertainty

Most engineering design is moving toward probabilistic methods, which combine the probability that an event will occur with a measure of its relative consequence. When employed properly, probabilistic methods used during design can provide a rational approach to determining inherent risk within a given design, and provide guidance for the application of appropriate safety factors.

However, in channel design, vessel design and waterway management today, there are no methodologies for implementing risk and uncertainty. The primary difficulty is the lack of clear, objective means to measure risk, safety, efficiency or reliability. Until procedures are established for incorporating these issues into a design, the designs will continue to be driven virtually exclusively by economics with possibly some environmental considerations included in the process. Despite significant efforts by numerous parties to incorporate environmental sustainability into channel design and operations, even the environmental issues are is not always well implemented since there are no universally recognized or commonly applied standards or methodologies for environmental values and liabilities.

Suggested Changes to Channel Design, Ship Design and Waterway Management Criteria

Channels and vessels need to be aware that the other group exists – during their respective design phases, as well as during operation and waterway management. Without channels and maritime transportation, most international commodities could not be traded economically. Without vessels, there would be no need for channels. Just as most engineers create designs with manufacturability in mind, channel and vessel designers need to design channels and ships with navigability in mind.

Recommendation: Obtain more full-scale data of vessels transiting restricted waterways. Basic hydrodynamics and vessel-channel interaction in restricted waterways are not well understood. Much more data such should be collected, assembled and analyzed to fully understand and quantify maneuverability dependence of a variety of vessels types, in shallow and restricted waterways. This data could then be implemented to improve and validate navigation simulators.

Recommendation: Establish guidelines and measures of vessel maneuverability in restricted water. A design standard for shallow and restricted-water maneuvering should be established. In addition to ensuring that ships can be controlled when operating in channels, such a standard could also be used to improve the safety of navigation and protection of the marine environment. Although ships may spend 90 – 98 percent 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, allisions, 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 akin to assuming that an airplane will be able to takeoff and land if its in-flight controllability is adequate.

Recommendation: Establish measures of channel efficiency and maneuverability. In addition to establishing a measure of relative maneuvering capability for vessels, channels should also have a similar relative measures to alert operators of potential challenges of a waterway. The impact of tug assist use in waterways should also be studied.

Recommendation: Establish a measure of quantifying factors such as safety, efficiency, and reliability. In order to achieve the mission as set out by many organizations involved in navigation to improve safety, efficiency, etc., these concerns must be better defined and measures for recognizing them must be developed.

Recommendation: Continue to improve methods to promote environmental sustainability. Nearly all organizations involved in waterway design and management promote beneficial environmental actions and should continue to do so. However, there are still numerous challenges regarding conflicts between environmental idealism and other projects or efforts. Perhaps too often, environmental interests attempt to impose unrealistic environmental expectations on a particular sites or activities, such as “no change,” or reversal to the environmental climate of a prior specific time. Any interaction – and often even no interaction – with nature will effect change; true environmental success is determining how to responsibly manage the change toward continued environmental sustainability.

Recommendation: Increase coordination between agencies. As discussed in the *Maritime Trade and Transportation* report (1999), there are numerous global and local maritime data integrity issues that presently exist and need to be addressed in order to improve data analysis. Albeit, many challenges exist since even in a localized project; data and logistical coordination between numerous governmental and private agencies is necessary for any waterway project design and management. Improved coordination can only enhance waterway success.

Recommendation: Establish technical feedback between vessel & channel. As mentioned previously, vessels are often designed with little or no consideration of restricted waterway behavior. Likewise, channel design rarely looks to optimize vessel maneuverability and efficiency. Understanding the interaction between the vessel and the channel is essential to improving waterway navigation and management.

Recommendation: Establish a means of continued channel usage assessment. Channels are often used by vessels that are larger than – or in some other way different from – those that they were originally designed to accommodate. There should be a tracking mechanism to identify when channel usage is becoming too risky and proactive measures should be taken to improve the situation.

Final Recommendations to Ensure Safe and Efficient Movement of Ships through Channels

It is apparent that channels should be managed as a system. This is in contrast to the current regime, which is focused on individual components, e.g. the channel, the ship, particular navigation information systems, etc. In other words, the channel is seen as a compilation of

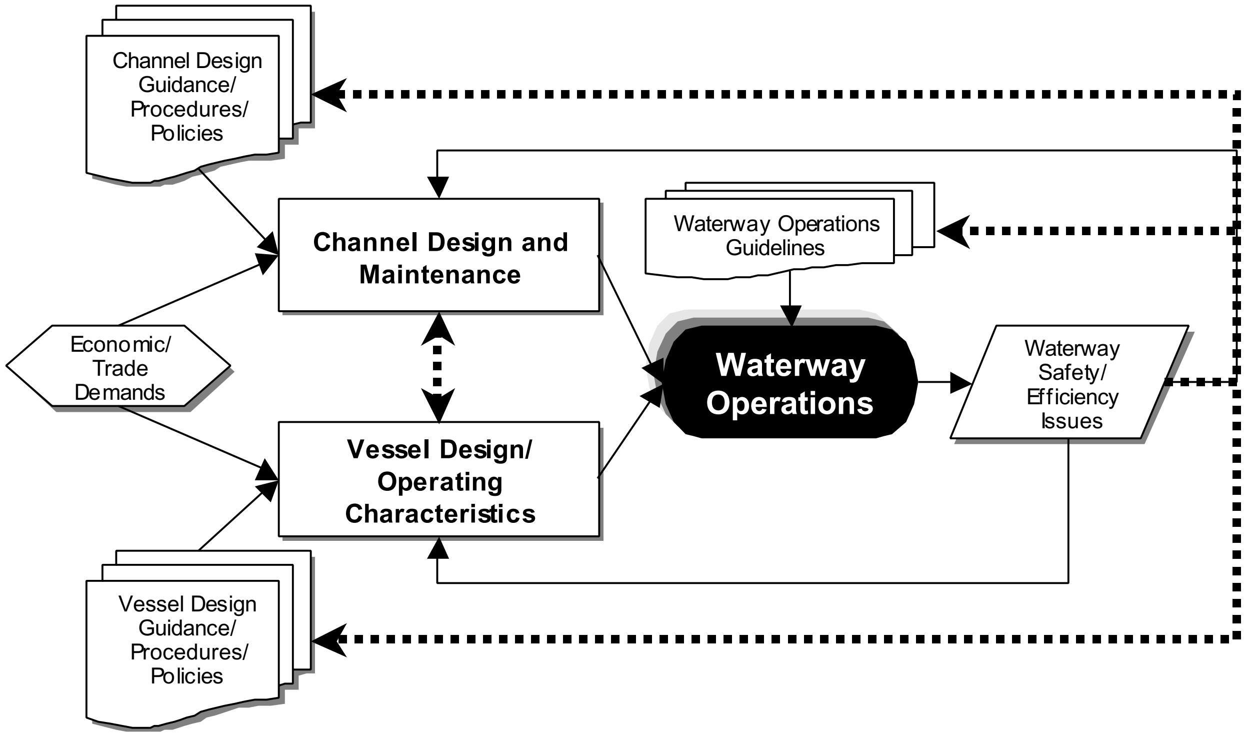

Figure 5: Feedback is required for all elements of the waterway system

components rather than as an integrated whole. Integrated management is needed to optimize the various components that comprise the channel.

Integrated management also requires closer coordination between all of the agencies and parties that have an interest in the channel. In the U.S., these include numerous federal, regional, state and local governmental agencies, private interests such as the local project sponsor, ship operators, and the local pilots' association. Closer coordination is needed to ensure that channel management is not overly focused on one particular aspect, e.g. channel depth, but is instead as holistic as possible. It was suggested that forums such as harbor safety committees could contribute to improved channel management by providing a venue that promotes this type of coordination.

Finally, navigation projects should have a mechanism for continued assessment and technical feedback (as shown in Figure 5). Although there may be resistance or concern that review could reveal negative information about a project, such fears are usually unfounded and much positive information can potentially be revealed and otherwise "hidden" benefits can be realized. Continual feedback and assessment will also assist in the development and incorporation of objective methodologies to improve waterway safety and efficiency models.

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