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Manoeuvrability of vessels in inland waterways and safety of navigation

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ABSTRACT

A green and sustainable mode of transport, the inland waterway transport in India will see accelerated growth with the new Inland Vessels Act, 2021. This increased traffic growth in restricted waters will lead to economic, environmental, and safety challenges. Good manoeuvrability of inland vessels is critical to resolve these concerns. The world over, inefficient manoeuvring has resulted in several incidents which have affected the safety of navigation and maritime trade. Manoeuvrability of seagoing vessels must meet the minimum standards as per International Maritime Organization (IMO) Resolution MSC.137(76) and the MEPC1/Circ850/Rev.3 guidelines. In comparison, only a few countries, river commissions, and classification societies have specified criteria for navigation tests for inland vessels, and this does not include India. Manoeuvrability criteria and results of the tests are essential to facilitate the safe movement of vessels. This article discusses the results of full-scale manoeuvrability tests of inland vessels conducted by the author on India's national waterways and the Indo-Bangladesh Protocol route. It proposes manoeuvrability criteria for inland vessels plying in the inland waterways of India, including cross-regional protocol routes. The article also recommends measures to improve the safety of navigation in inland waters.

KEYWORDS
Manoeuvrability; sustainable; inland waterways; navigation safety; environment; criteria

Introduction

Over 90 per cent of international trade by volume moves by ships. For the movement of goods in the hinterland, inland waterway transportation (IWT) is considered the most sustainable, economical, environment-friendly, socially beneficial, and optimised solution.[1] According to a report by the United Nations Conference on Trade and Development (UNCTAD), seaborne trade is expected to grow by 4.8 per cent in 2021, whereas the global shipping fleet, that grew by 4.1 per cent in 2019–2020, is expected to grow by 1.6 per cent in 2020–2021. With imported cargoes accounting for 65 per cent and exports accounting for 58 per cent of total world sea trade in developing economies in 2019, the soaring maritime trade reflects increasing traffic in the ports and approaches. This makes effective guidance and management of traffic crucial. The drive for efficiency

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has led to increased dimensions of the vessels and enhancement of port infrastructure and waterways.[2]

To make the shipping sector more sustainable, regulations, new technologies,[3] guidelines for the design of port and harbour approaches, vessel traffic systems, locks, etc., have been published by the Permanent International Association of Navigation Congresses (PIANC). As seaborne traffic is global, it is primarily governed by International Maritime Organization (IMO) instruments on maritime safety, security, navigation efficiency, pollution control from ships, and so on. The standards have been developed considering the views of all stakeholders, including developing and least developed states, and are governed by IMO's strategic plan.[4] This ensures that the design of ships, including the operating systems, is developed based on the best research and technology in the world, and that the seagoing vessels are manned by trained and certified crew.

On the other hand, trade carried through inland waterways of a country by inland vessels, or IWT, is a regional trade and requires to be competitive in cost compared to road and rail modes. Its development is based on the characteristics of the waterway, regulatory mechanism, financing, technology, and availability of cargo. The development of an IWT ecosystem has happened in some industrialised economies, namely, the United States (US), Russia, and Europe, where the waterways are well-designed with fewer bends of large radius of curvature and regular navigation channels. In China, the growth of IWT began in 1978 when it adopted the "Transport Science and Technology Development Plan" to modernise transportation and it is continuing till date. With over 40 years of sustained reforms, development plans and continuous high-level support, like policy changes, government incentives, and financial and technical support of international funding agencies such as the World Bank and Asian Development Bank (ADB),[5] the capacity of IWT in China, in 2018, was 12.6 billion tonnes.[6] In comparison, the volume handled by the IWT system in the US was 551 million tonnes,[7] while the European inland waterways handled 523 million tonnes in 2019.[8] The Yangtze, the Pearl, the Grand Canal (all in China), the Rhine, the Mississippi, and the Mekong are the six waterways that handle over 100 million metric tonnes (MMT).[9]

Meanwhile, in India, the growth of the IWT sector resumed with the setting up of the Inland Waterways Authority of India (IWAI) in 1986. In 2014, it got a significant boost with the implementation of the Jal Marg Vikas Project – capacity augmentation of the Ganga–Bhagirathi–Hooghly river system, National Waterway-1 (NW-1) – with the technical and investment support of the World Bank. The vessel construction subsidy,[10] enactment of the National Waterways Act, 2016, to add 106 additional national waterways, and the recent enactment of the Inland Vessels Act, 2021, was done to introduce a uniform regulatory framework for inland vessel navigation across the country. This has led to the growth of traffic on waterways.[11] The traffic handled by IWT in 2019–2020 was 73.6 million metric tonnes, and in 2020–2021 – is 83.61.12 million metric tonnes, with a yearly growth of 13.54 per cent.[12]

The Protocol on Inland Water Transit and Trade (PIWT&T) between India and Bangladesh, an agreement that allows vessels of either country to travel through specified river routes (Indo-Bangladesh Protocol [IBP] routes), has been regularised, with new ports and routes being added.[13] India's Ministry of Shipping has signed several memorandums of understanding (MoUs) for allowing the movement of vessels on the IBP route. The latest one allows the use of Mongla and Chattogram Ports for the movement of

Indian cargoes. The 20 national waterways of the North-East, NW-1, and IBP routes together become an integrated waterway network of over 2600 kilometres (km).

This integrated network (see Figure 1) with the IBP route handled 13.66 million metric tonnes[14] MMT of cargo in 2020–2021, which is expected to increase to 14.78 million metric tonnes in 2021–2022.[15] The primary commodity transported on the waterway network was fly ash and stone chips. Over 1900 inland vessels were used to transport fly ash between Haldia/Kolkata to Mongla/Narayanganj in Bangladesh in 2020. These vessels were not tested for manoeuvrability as no specified tests and criteria exist.

Classification of inland waterways and types

Different dictionaries define a waterway as a canal, river, or narrow sea channel that ships or boats can sail along. Further, it can be broadly categorised as a natural or artificial waterway. A natural waterway may be a river perennial in nature, channelised and trained rivers, sea creeks and fjords, affected by different strengths and directions of water flows/currents. The type of river bed is also crucial as a sandy river bed poses a lesser hazard than a rocky or rugged bed. An artificial waterway can be a canal, navigation channel, or lake with and without lock systems.

There are no standard criteria for the classification of inland waterways. In fact, classification across different regions has been done based on ordering and organisation of the components of river infrastructure according to the given criteria.[16] These criteria include the width and depth of the waterway, the radius at bends, horizontal and vertical clearances of bridges and cables across the waterways, the current flows, type of waterway

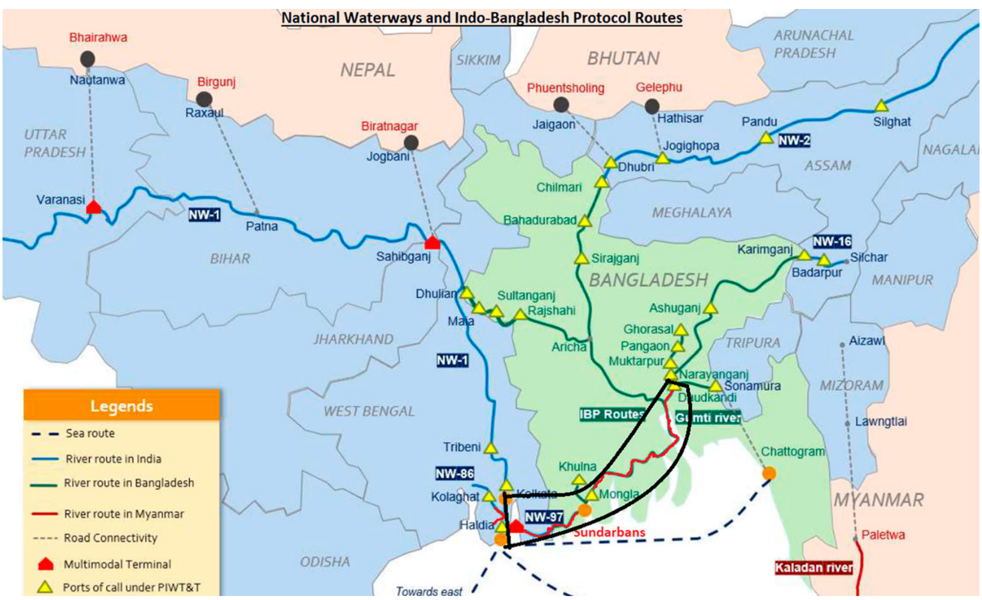


Figure 1. National waterways and Indo-Bangladesh protocol routes. Source: Inland Waterways Authority of India.

bed, wind extremes, etc. Thus, the contours of the navigation route to be followed by inland vessels get fixed.

The IWAI has classified waterways (Classes I–VII) on the basis of the depth, bottom width, bend radius, vertical clearance, and distance between piers, according to the type of waterway, that is, canal or riverine. The regulations also specify the approximate size of vessels and cargo-carrying capacity respective to the class of the waterway.[17] The European classification of waterways (Classes I–VII) is according to maximum dimensions of the ships operating on specific waterways; and Class IV can be considered as inland waterways of international importance in the pan-European network ("E waterways"), like the Rhine, the Danube, and the Elbe. The European Conference of Ministers of Transport (ECMT) criteria for determining class are the horizontal dimensions of the vessels or units (length and maximum length); and vertical criteria, such as draft and maximum height under bridges.[18] The difference between the inland waterways of India and Europe is that the European waterways are a network of canals, locks, and trained channelised rivers. In contrast, Indian national waterways are majorly natural flowing perennial rivers, thus have more bends with a smaller radius of curvature. Also, Indian national waterways are similar in characteristics to the Yangtze waterway but have a lesser water depth. Hence, inland vessels in India need similar manoeuvrability as in the Yangtze.

Accidents and analysis of navigation safety

Safe navigation of ships is vital for reliable maritime trade and IWT. More than half the number of accidents are reported in ports and approaches.[19] Several accidents have occurred in port approaches and navigation channels, like the grounding of *MV Anglo Alexandria* in 2019[20] and *MV Belita* in 2020, both of which blocked the mouth of the Mississippi River navigation channel, delaying over 50 vessels.[21] Recently, the grounding of an oil tanker, reportedly caused by a malfunction with its steering controls, led to traffic closure in Bosporus Strait.[22] Another example is the closure of the Suez Canal for six days due to grounding of *Ever Given*, holding up an estimated $9.6 billion of trade along the waterway each day; also, in 2016, the groundings of vessels *MSC Fabiola* and *Maersk Shams* had blocked traffic in the Suez.[23] In 2021, the collision between the liquified gas carrier *Genesis River* and *Voyager Tow* in Houston Ship Channel in inland waterway resulted in the closure of the channel for two days. Closer home, the grounding of *Kota Rajin* blocked the navigation channel to Kolkata earlier this year.[24]

Though the causality investigation is ongoing for most of the above-mentioned accidents, media reports suggest that the vessels ran aground due to manoeuvring difficulty caused by strong winds, hydrodynamic interaction, or steering malfunction. It is evident that the groundings, contacts, and/or collisions within ports are the most prevalent accidents in adverse weather conditions.[25] In 2018, 140 incidents, that is, 56.9 per cent, in the Baltic region took place when the ships were approaching the ports or even within the port area.[26] The National Transport Safety Board (NTSB) reports that the probable cause of the collision in the Houston Ship Channel is caused by the hydrodynamic effects of the banks and increased the interaction effect with other vessels and manoeuvring stability vessels.[27]

Even in India, collisions, contact, and groundings form nearly two-thirds of the total number of accidents that have been reported to the administration. Most of these incidents occurred during berthing, ship-to-ship (STS) operations, or in port approaches. The casualty investigation report by Director General of Shipping highlights that the officers navigating vessels involved in collision accidents lacked familiarity with the ship's manoeuvring characteristics and the effect of environmental, topographical, and passing traffic on vessel manoeuvring.[28] In the Indo-Bangladesh integrated eastern waterway grid also, accidents have led to blockage of routes. For instance, recently, the route was blocked because a barge sank in the waterway at Namkhana Bridge and another barge capsized in theHooghly following a collision.[29]

Manoeuvrability of vessels and navigation safety

Manoeuvrability has two elements: the ability to maintain stability in a course or turn and controllability. The ability to initiate a course change and check a course change quickly constitutes controllability in the manoeuvring of a vessel. In physics terms, manoeuvrability is divided into steady states in terms of course keeping and turning, the ability to change, and the rate of change between steady states.[30] The turning capability and route retention capability are contradictory design features.

Manoeuvrability of seagoing vessels

A seagoing vessel mostly steers a straight course for long distances and alters course to mainly follow the route or avoid a close quarter situation with another vessel. The manoeuvring requirement for navigation at sea is that the vessel should have good course stability, ability to maintain course in all weather conditions, and, if required, be able to turn into or away from the seas and waves.

When balancing the two aspects of manoeuvrability, that is, course stability and course changeability, a seagoing vessel will usually be more direction stable as compared to the ability to change course. This is because a seagoing vessel has to sail long distances on straighter courses across oceans. Hence, it is required that the vessel maintain course with minimum rudder application so that speed loss due to frequent rudder application is reduced.

Speed, control systems, and rudders for seagoing vessels are designed according to the rules of classification society and of flag administration, and need to satisfy the manoeuvrability criteria as per IMO Resolution MSC.137(76) for calm and unrestricted waters and propulsion power criteria in adverse conditions as per the IMO's Marine Environment Protection Committee (MEPC) circular.[31]

Manoeuvrability of inland vessels

The inland vessels primarily operate in restricted shallow flowing waters in dynamic serpentine channels that vary seasonally in depth, width, and bend radius. Thus, the manoeuvring requirements for inland vessels must account more for course-changing than course-keeping capability and be according to the operational area and dynamic requirement.

Since inland vessels regularly ply in restricted shallow waters, it is to be appreciated that the directional stability and manoeuvrability of the ship significantly change with the depth to draft ratio.[32] Shallow waters affect manoeuvrability of vessels in a severe and complex manner: "for example, a ship that turns to starboard in deep water may well turn to port in shallow water". The effect of shallow water on manoeuvring behaviour of ships can be predicted based on empirical formulae, modelling, and theory, though both experienced hydrodynamicists and mariners have varying opinions in this regard.[33] Simulating complex flows experienced around ships when manoeuvring in shallow water is still rather challenging.[34]

Navigation of vessels in varying strong inhomogeneous currents poses a different challenge, especially with flowing currents. Theoretically, the turning circle diameter may be identical (and show up the same on the water surface), but the track on the ground will be broader, with a longer reach, when vessel is navigating in the direction of the current and the track will be narrower, with shorter reach, when the vessel is navigating against the current (Figure 2).

Internationally, no standard criteria to test the manoeuvrability of inland vessels have been specified, and this is rightly so due to varying types of waterways. The Rhine and Danube river commissions, few classification societies, and some counties, like China and Russia, have notified tests and criteria for the inland vessels plying in certain waterways. India, Bangladesh, and the Indian Register of Shipping (IRS) have not specified any rules or standards to test the manoeuvrability of inland vessels.

The inland masters in India, who are tasked with navigating vessels in shallow and restricted waters, have no or little information on manoeuvrability and limited formal training. Hence, to reduce the number of collisions, groundings and near misses in inland waters, the criteria for manoeuvrability tests of inland vessels, including in

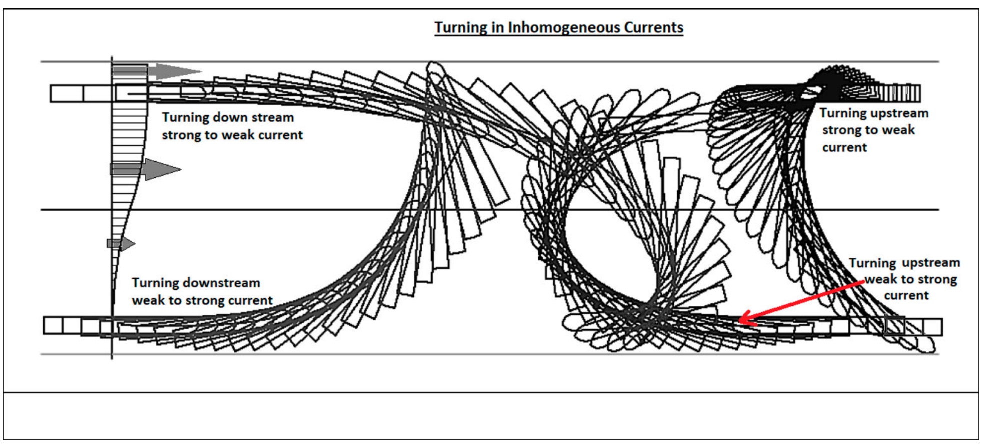


Figure 2. Effect of inhomogeneous current on turning circles. Source: Adapted from Andreas Gronarz, "The Influence of Inhomogenous Current on the Ships Motion, n.d." https://www.dst-org.de/wp-content/uploads/2016/01/Gronarz-The-influence-of-inhomogeneous-current-on-the-ships-motion.pdf (last accessed December 19, 2021).

Note: Upstream and downstream turns in inhomogeneous current result in the vessel overshooting its normal track, thus requiring better controllability (manoeuvrability).

shallow waters, need to be established. As inland vessels operate in shallow and very shallow waters, it is important that the manoeuvring tests are performed and if required control systems in form of kort nozzle or bow thrusters are fitted. Navigation tests like zigzag, evasive manoeuvre should be conducted and compared with specified criteria and results of the tests provided on vessels for the guidance of inland masters. If the navigation tests are not satisfactory then necessary guidance on manoeuvring be provided to the master. Subsequent vessel designs of the similar form may need modification of the rudders or additional control systems like kort nozzle, bow thruster or rudder.

The effect on inland vessel manoeuvres corresponding to limited channel breadth and shallow water is generally not taken into account in the initial ship design, especially in the developing countries. The available knowledge is insufficient as research into inland ship optimisation is usually omitted from the design process due to the high cost compared to the design budget. Moreover, "the lack of available data has prevented the development of adequate empirical power prediction methods for inland ships".[35] Hence, there is a need for further research and analysis of the propulsion power, control systems, and rudder design of the inland vessels, in particular with regard to the environment they operate in.

Navigational requirements of inland vessels based on full-scale tests

With nearly fixed physical parameters of inland waterways and optimally designed vessels, the external dynamic factors, namely, the changing depths, current strength and direction, and traffic, present considerable navigation challenges for navigators. On analysing a typical riverine waterway like NW-1 (the Ganges) and IBP route, it is found that the inland vessels need to execute certain manoeuvres regularly.

In inland waterways, navigation manoeuvres need to be executed at both full and slow speed. Also, the vessel is navigated down the river, that is, with the current in the same direction as the vessel's course, and upriver, when the current in the opposite direction. All these factors along with manoeuvring requirements to negotiate different types of bend and traffic situations (see Figures 2, 3 and 4) need to be considered when specifying the manoeuvring criteria for a vessel. Reserve power and speed are required to counter the strength of the current to round the bends by providing necessary thrust flow to the rudders to improve manoeuvrability. The situation becomes more complex with frequent overtaking of vessels or when meeting vessels coming from the opposite side in narrow waters. All these factors need to be considered when specifying the manoeuvring criteria for a vessel. The limited cross-section clearance of vessels when navigating in canals and locks, and when involved in overtaking or crossing situations, reduces the critical ship speed range due to their unfavourable blockage ratio.[36] The vessels, thus, need to be manoeuvrable at such low speeds.

Most of the IBP route is tidal and hence, navigation with the following current is preferred for fuel efficiency and better under-keel clearances, due to which the reverse traffic is limited. Night navigation is not allowed in a certain waterway stretch of Bangladesh. Also, Indian vessels, when navigating through the IBP route, need to take local pilots in Bangladesh waters. In contrast, night navigation is permitted in the Indian stretch of the IBP route, and that too without pilots. Several close-quarter situations have been reported during transit in the Indian stretch of the IBP route. The

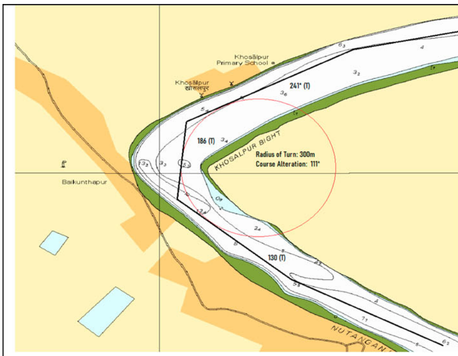
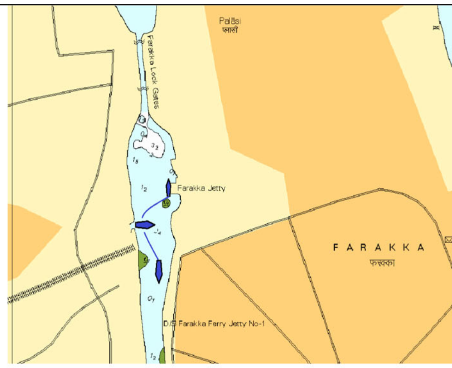
	
Frequent course change, turning manoeuvre and yaw check.	Stop-and-go astern and stern manoeuvre, berthing and unberthing.
	
Actual track plot of an inland vessel making a U-turn type of turn on the Ganges NW-1.	Actual track plot of an inland vessel making S-bend manoeuvre along IBP route.

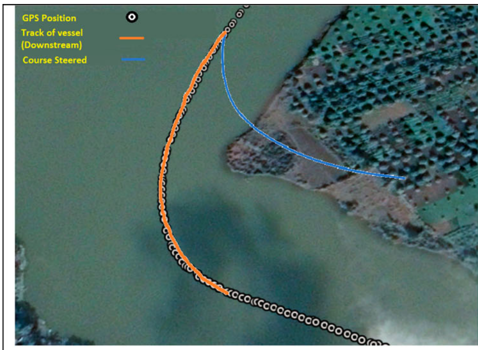
Figure 3. Manoeuvres in inland waterways. Source: Vessel Global Positioning System (GPS) coordinates imported on Google Earth and IWAI chart by the author.

Note: The figures show that there is regular requirement of course change and yaw checking in riverine waterways to negotiate the bends.

channels, in certain parts, are narrow and the vessels need to hold position to allow passage of another vessel. Most national waterways in India have similar characteristics. Hence, there is a need to establish manoeuvrability criteria and navigation tests for inland vessels for safe navigation.

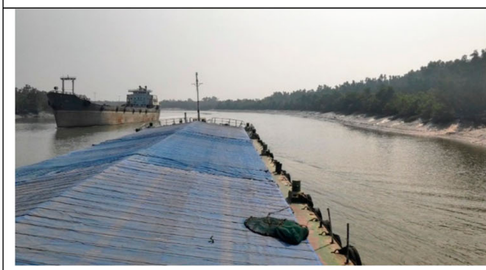
Considerations for manoeuvrability criteria of inland vessels

It is critical to frame the criteria for manoeuvrability of inland vessels in India for the safety of navigation. The inland waterways across the globe have varied physical, topography, bathymetry, and flow conditions, with different types of vessels and configurations operating on them. Accordingly, the rules and standards have been laid down by various organisations and countries. Though guidelines may be drawn from them, they need to be specific to the Indian waterways.



The large drift of vessel when executing a turn downstream shows the need for better controllability and understanding of the turn.

Inland vessel inside Farraka Lock.



Crossing and overtaking situation in narrow channel with several sharp bends (IBP route).

Figure 4. Navigation and traffic challenges. Source: Photos by author, clicked on the mobile phone.

These criteria must be objective, verifiable, realistic, and based on consistent, sound and simple physical principles.[37] The considerations for manoeuvrability criteria of inland vessels are based on literature review, existing standards promulgated by the regulating agencies (China, Russia, European Union, Central Commission for the Navigation of the Rhine [CCNR]), full-scale tests of four inland vessels, in-service recording of manoeuvre of vessels, and sailing experience of the author on the inland waterways.

Speed ahead

The inland vessel must have minimum ahead speed to negotiate the bends downstream and have sufficient power for upstream navigation. The vessel will also counter strong river currents (~3 m per second [m/s]) in shallow waters as the depth to draft (h/T) ratio in inland waters is likely to be about 1.2. For criteria for minimum speed ahead, the critical speed in shallow water, speed of the current, and reserve speed to counter current spikes in bends to augment the rudder efficiency must be taken into account.

Speed astern

Criteria for minimum astern speed are essential for inland vessels as they regularly operate in favourable and adverse current flows, in restricted width of waterways, and with frequent crossing traffic requiring them to take all way off at short notice. The astern speed criteria need to take into account minimum speed strength of the current and additional reserve for manoeuvrability when going astern. For instance, the towboats in the US navigate downriver through sharp bends by flanking, where astern speed works on flanking rudders located in front of the propellers.

Course-keeping ability

For inland vessels, though the focus of design is more on turning ability, course keeping is equally important to limit the instability of the vessels. The amount of rudder required to maintain course may be specified similar to the standards defined for the manoeuvrability of inland vessels in the Yangtze River (JT/T 258-2004).[38]

Turning ability

An inland vessel is required to make sharp turns in limited space. The turning diameter is inversely proportional to the rate of turn (ROT). This turning ability, determined by the ROT, is tested by conducting turning circle manoeuvres at operational speed. The criteria for the ROT or turning diameter are dependent on the radius of bend the vessel is to navigate. Further, the turning ability is verified by doing a turning test with the rudder hard over. A turning test at 20° must also be done.

Yaw-checking ability

After initiation into a turn, the yaw rate changes. Therefore, on achieving the desired course, the yaw needs to be checked by applying steering controls. The yaw-checking ability of the vessel is critical to avoid overshoot of the course, thereby reducing cross-track tendency and avoiding close quarter situation with a vessel. The yaw-checking ability criterion depends on the navigation channel's width and the speed of the current. Further, it is verified by doing a 10°/10° or 20°/20° zigzag test.

Stopping ability

The stopping ability is important for a vessel to avoid an incident when faced with a navigation hazard at short notice to be stopped at the shortest possible distance.

Stern steering

The capability of a vessel to be able to navigate or control stern is important for inland vessels to do flanking or round the bend with the current. The stern is steered into the current in order to maintain a position for a short time to allow the passage of another vessel rounding the bend.

Full-scale test of yaw-checking ability (by the author)

During full-scale tests by the author, two vessels could not complete the zigzag tests when sailing downstream and additional helm was required to control the continued yaw.

The 10°/10° zigzag manoeuvre is obtained by reversing the rudder alternately by 10° to either side at a 10° deviation of the ship's heading from the heading at start of the test. For instance, as shown in Figure 5, a vessel was steering 090° and the rudder was put 10° to port and when the heading changed to 080°, the rudder was put 10° to starboard, but the vessel continued to turn to port till 083°, and then commenced turn to starboard, hence the first overshoot was 7°. The rudder was kept to 10° starboard till heading changed to 100°, when rudder was put 10° to port. The vessel continued to turn to starboard and the overshoot continued till 16° and increasing, when additional rudder was given to control the swing. Thus, the yaw-checking ability of vessel appeared to be unsatisfactory. The full-scale yaw checking test data of the said vessel do not meet the yaw checking criteria of the Yangtze waterway.

The full-scale tests were conducted on vessels with twin screws and twin rudders. These vessels met the IMO manoeuvrability 10°/10° zigzag test criteria of 1st and 2nd overshoot. However, they did not meet the requirements specified by Chinese authorities for navigation in the Yangtze with turbulent waters (JT/T 258-2004), which is of a similar nature to most national waterways in India. The vessels of the length of about 50 metres (m) constitute about 40 pre cent of the total vessels plying on IBP routes, and these vessels are fitted with a single engine and single plate rudder. The manoeuvrability of these vessels is likely to be poor and may cause navigation safety issues.

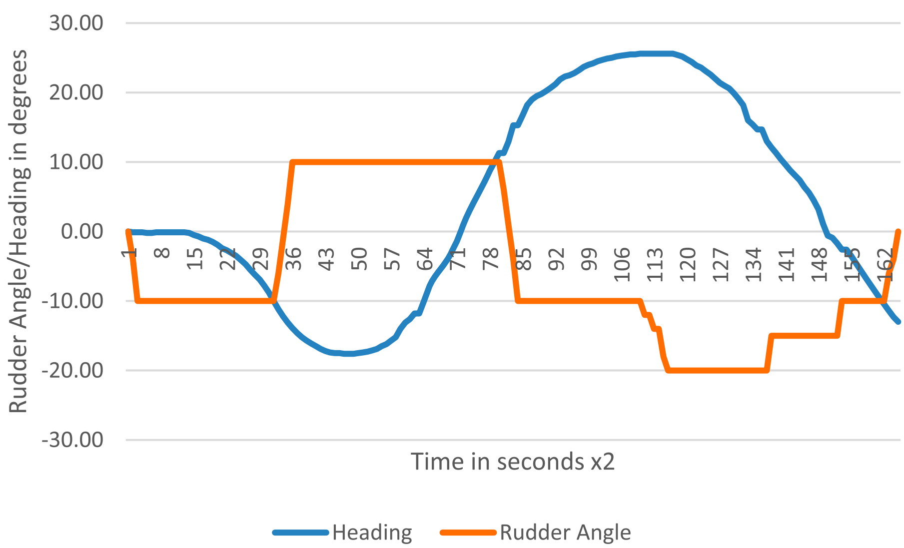


Figure 5. 10°/10° Zigzag test result of vessel Pradyun (excessive overshoot and additional helm to return). Source: Author.

Note: The vessel heading track is in blue: 1st overshoot: 7°; 2nd overshoot: 16°.

Manoeuvring criteria of inland vessels of other countries

The manoeuvring performance of a vessel is judged based on navigation tests meeting the criteria that are characteristics of several manoeuvres. The IMO, United Nations Economic Commission for Europe (UNECE), CCNR, and waterway administrations in Russia and China have specified manoeuvres and their requirements. The Yangtze riverine waterway is similar to the riverine national waterways in India and the IBP route. Hence, the regulations adopted by the Chinese classification society are described in detail later in this section.

The Economic Commission for Europe's (ECE) Resolution 61 on "Technical Requirements of Inland Navigation Vessels"[39] regulates the minimum requirements of manoeuvring behaviour of inland vessels registered in European Union countries, based on navigation tests for speed (forward), stopping capacity, capacity for going astern, capacity for changing course, and turning capability. The classification society has adopted these requirements in its rules. The CCNR has issued manoeuvring criteria for vessels sailing on the Rhine,[40] regarding speed, stopping and turning abilities, and evasive capabilities. The Chinese classification society has divided the river into navigation areas according to hydrological conditions of the river, in increasing order of difficulty, as A, B, C, and J (J1: very turbulent, J2: turbulent), and developed the following regulations for manoeuvrability of inland vessels.

The maximum length of the vessels or convoys is to be 150 m. The requirements to be met for each manoeuvre and each navigation class are given in Table 1. The following variables have been used in the table:

1. ΔC_0: the allowable course variation at $\delta = 0°$, measured over 3 min;
2. δ_0: the allowable rudder variation to keep a prescribed course for 5 min;
3. $y_{0\text{-}15}$: the minimal allowable yaw rate when moving towards 15°/minute with a rudder angle of 15° in degrees/second;
4. D_0 and A_h represent the dimensionless tactical diameter and track reach; and
5. δA: the allowable rudder variation to keep a prescribed course astern for 3 min.

The manoeuvres must be carried out at a steady speed, the value of which is not specified. The actual full-scale tests have been compared in Table 1.

Improving manoeuvrability and navigation safety

The rudder, propulsion, and steering systems on inland vessels plying in the subcontinent are conventional. Multiple rudders enhance manoeuvrability of inland vessels by increasing the

Table 1. Validation of inland vessels with criteria by Chinese classification society.

Vessel identification	Course-keeping ability ΔC_0 (°)	δ_0 (°)	Course-change ability $Y^{\#}_{0\text{-}10}$	Steady turning quality D_0	Stopping quality/track reach A_h
J turbulent class	< 3.5	< 4.5	> 0.55	< 3.5	< 2.5
WAAI	6	5	0.56	2.75	1.95
PRDN	7	5	0.43	2.04	2.32
DVSN	5	6	0.51	2.46	2
RNTR	4	5	0.45	2.81	2.31

Source: Author.
Notes: #The course-change ability criterion is > 0.83 radians/second for 15° rudder, but tests were done for 10° and hence, it has been interpolated prorate basis. WAAI, PRDN, DVSN, RNTR are vessel identification codes.

rudder area. Therefore, fitting another rudder, modifying the rudder profile to flap rudder or more complex ones, increasing the flow velocity to the rudder, and fitting bow rudder and thrusters help in greater manoeuvrability of vessels.[41] The inland vessels in the US and Europe have been using such systems and the technology is readily available today. For existing vessels, 10°/10° and 20°/20° zigzag manoeuvres tests can be done to determine manoeuvrability and if it is found to be poor, then manoeuvrability improvement may be undertaken using any of the above-mentioned mechanisms. When designing new inland vessels, the steering systems used on inland vessels in the US and Europe may be taken into consideration.

To improve the safety of navigation, it is recommended to make it compulsory for vessels to take the services of local pilots when navigating in the Indian portion of the IBP route. The IWAI has deployed River Information System (RIS), with manned stations, that can track vessels fitted with the Automatic Identification System (AIS). The station will be able to monitor and, if required, guide or warn them of danger only if the vessels are fitted with AIS that is "on". The vessel traffic service by Syama Prasad Mookerjee Port, Kolkata, is also AIS based. At any given time, there is more inland vessel traffic than sea-going vessels in the navigation channels of the region. Compulsory installation of AIS on all inland vessels will assist in tracking and avoidance of close quarter situations with other vessels by positive identification, communication, and detection of vessels behind bends.

Conclusion and recommendations

The traffic on national waterways and the IBP route is likely to grow with a more significant number of vessels transiting through the restricted, shallow, and sensitive waterways. The inland vessel fleet in India is yet to grow and inland vessel rules, under the Inland Vessels Act, 2021, are in the drafting stage. For safety of navigation in inland waters, it is suggested that:

1. Manoeuvrability criteria for inland vessels plying on the national waterways and IBP routes are drafted, discussed, and enacted for all new vessels.
2. Navigation tests for manoeuvrability of existing vessels be conducted, along with the adoption of the best possible solution to improve manoeuvrability; or operational guidelines should be suggested for the vessels.
3. Standard operating procedures on manoeuvring inland vessels through congested waters be circulated among inland masters.
4. All inland cargo vessels plying in Indian inland waters be fitted with AIS.
5. Pilotage should be made compulsory for all vessels in the Sundarbans.
6. Inland vessel masters should be trained in handling vessels using the manoeuvring characteristics of the vessel and new steering control systems, if fitted.

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