# *MODIFICATIONS IN DESIGN FOR IWT VESSELS*

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*Abstract*--This paper attempts to assess the viability of movement of passengers and freight by inland water transport (IWT) in India. The report highlights the design of concepts for container and bulk cargo transport. These concepts fulfill contemporary ecological demands, apply innovative technologies, and obey the existing waterway restrictions. The designs proposed are self-propelled vessels for container transport and barge train for bulk cargo transport.

***Keywords***
***B – Vessel beam (m)***
***cT – Train formation coefficient (RT/ΣRi)***
***F – Freeboard (H-T) (m)***
***FNh – Froude number based on water depth (v/√(g·h))***
***h – Water depth (m)***
***hW-LNRL – Water depth by LNRL (m)***
***hA-HWL – Air clearance over HWL (m)***
***H – Vessel height or depth (m)***
***L – Vessel length (m) r – Resistance ratio (Rwh/Rw∞)***
***Ri – Individual resistance of each barge (kN)***
***RT – Total resistance (kN)***
***Rv – Viscous resistance (kN)***
***Rw – Wave making resistance (kN)***
***T – Vessel draught (m)***
***v – Vessel speed (km/h)***

***Subscripts***
***h – Finite water depth (shallow water)***
***∞ – Infinite water depth (deep water)***
***OA – Overall***

## I. Introduction:

There are several definitions of optimal ship, one of them, define optimal ship as:

- Modern and environmentally friendly
- With low exhaust emissions
- With low fuel consumption
- Economical in operation
- Highly compatible with the waterway
- Have capability to align to the river
- Have minimal impacts on bank vegetation and fish fauna.

## II. Restrictions of National Waterways

### 4.1. *Available Depth*

**Least available depth on NW-1**[2]

| Stretch | Distance | Least Available Depth |
|---|---|---|
| Allahabad to Ghazipur | 370 km (230 mi) | 1.2 to 1.5 m (3.9 to 4.9 ft) |
| Ghazipur to Barh | 290 km (180 mi) | 2 m (6.6 ft) |
| Barh to Farakka | 400 km (250 mi) | 2.5 m (8.2 ft) |
| Farakka to Haldia | 560 km (350 mi) | 3 m (9.8 ft) |

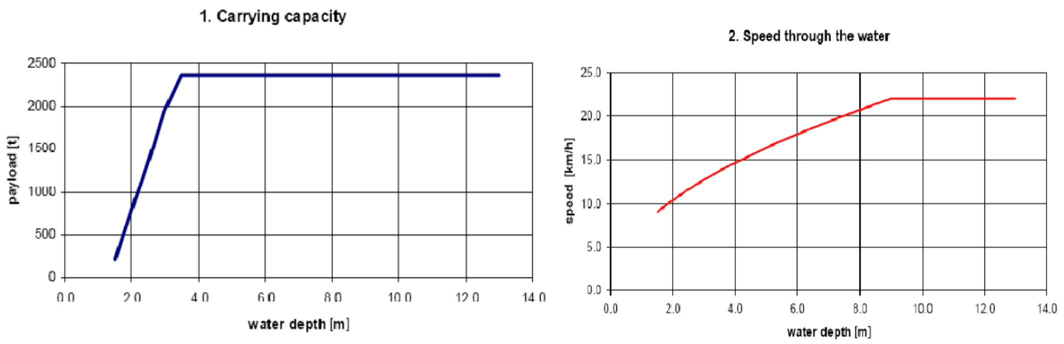


**Figure 2.1** Influence of water depth on ship payload and speed (Source: Zigic, 2008)

**4.2. *Shallow water resistance***

Shallow water hydrodynamics is of primary importance for inland vessels and particularly for fast inland vessels. In shallow water, vessel resistance is very much different than in deep water, and may play the most important role in inland vessel design (see power-speed diagram,). Resistance RTh shows a pronounced peak (resistance increases) at the critical Froude number (critical speed which depends on water depth). This may be explained with the growth, which is then followed by the loss, of transverse waves. So, although in the expression above the total resistance RT was mentioned, in the shallow water only one resistance component – the wave making resistance RW – changes dramatically (total resistance RT consists of viscous resistance RV and wave making resistance RW). This phenomenon may be well expressed through the ratio of shallow water wave resistance to deep water wave resistance r = RWh/RW∞. Following this logic, three speed regions may be detected:

- sub-critical region where the effects of water depth are almost negligible
- critical region where RWh increases dramatically (r is greater than 1)
- super-critical region where RWh may be smaller than RW∞ (r is a bit smaller than 1).

The increase of wave-making resistance – resistance ratio r – in the critical region is of primary importance for fast vessels and depends mainly on the ratio of h/L (where L is vessel's waterline length).

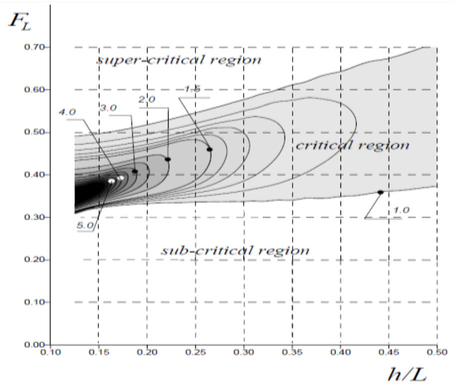


**Fig. 3.3** Shallow water resistance chart

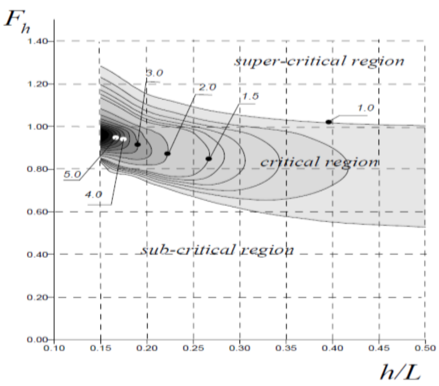


**Fig. 3.4** Shallow water resistance chart

*4.2. Propulsive efficiency in shallow water*

The denominator in the above equation ($\eta D \cdot \eta S$) is called the total propulsive efficiency, but since $\eta S$ is around 0.95 regardless of water depth (i.e. transmission losses are usually 5%), only $\eta D$ is of further interest ($\eta D$ is the propulsive efficiency, also called quasi propulsive efficiency). Propulsive efficiency variations in shallow water are exactly opposite to resistance, i.e. around the critical Froude number, $\eta D$ decreases compared to the value in deep water (curve $\eta D$ as a f (Fnh) has a pronounced hollow around the critical speed, specifically around Fnh $\approx$ 0.9). This hollow ($\eta D$ reduction), among other reasons, is explained by increased propeller loading due to increased resistance in shallow water.

***3.3. Wash problems***

High speed vessels generate large waves (followed by increase of wave-making resistance), which may cause environmental problems (bank erosion) and endanger other users of the waterway. Waves generated by forward motion of a ship are called wave-wash or just wash. The main wash problem is associated with the passage through a critical speed range and is particularly pronounced in shallow waters.

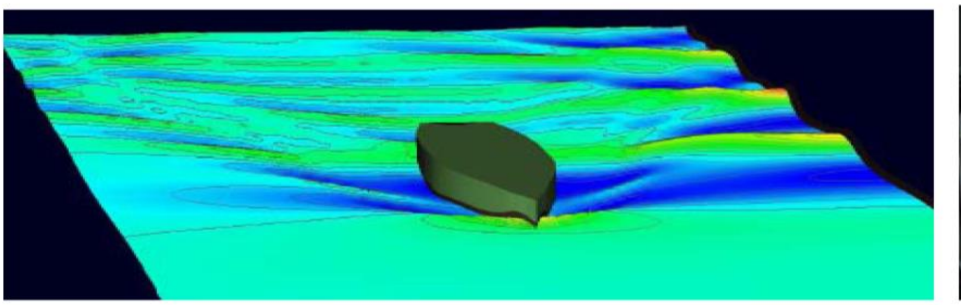

**FIGURE: Typical Fresh water wave system**

**5. Implications on ship's design**

Taking into account that

a) an IWW vessel should be designed according to the particular waterway, and

b) all-around clearance between the vessel (or her cargo) and bridge/river bottom/ lock-side should be at least 0.3 m, the maximal allowed vessel dimensions, with possible minor restrictions in sailing during the dry seasons, are -

T < 1.7 m (probably 2 m), B ≤ 11.45 m

T < 2.0 m (probably 2.5 m), B ≤ 23.4 m.

(Depending on Drafts in a particular region)

*5.1. Propulsion Power*

Obviously, it is of primary importance to reduce the power needed for moving the ship. This power is called the Brake power (PB); it depends on vessel speed (v), resistance (RT) and efficiency of the proposers ($\eta D$). In particular

$$PB = RT \cdot v / \eta D \cdot \eta S .$$

## III. Proposed features of Container ship concept

The objective here is to explain (in words) how successful shallow water container vessel could look like. Therefore, the recommended vessel dimensions and other important characteristics to be incorporated into design are the following:

• ***Draught (T)* – 2.5 m maximum** for three layers of full containers of average mass of 13 t. With two layers of full containers, draught will be **up to 1.85 m**. Nevertheless, according to transport statistics, on average 2/3 of all containers are loaded and 1/3 are empty (with a mass of ca. 2 t only). Therefore, it might be expected that in reality draught will be smaller than stated above. If reduced draught sailing would be necessary, a coupling train should be considered.

• ***Breadth (B)* – 11.65 m (cargo hold breadth just above 10.3 m)** allows abreast loading of four ISO containers or 2.50-2.55 m wide domestic containers. The competitiveness of IWT should be increased, hence a ship of width of 11.65 m can be chosen as a good overall compromise.

• ***Length (L)* – 104 m** follows from the desired **cargo hold length of around 80 m**. Within this length, longitudinally 13 TEUs may be stowed with 20-50 mm clearance between them (this requires top-lift transshipment with a spreader). A hold length of 80 m allows also a wide variety of other stowing possibilities, for instance (6x40' + 1x20'), (4x45' + 4x20'), (4xA1360+ 4x20'), (9xC745 + 2x20'), etc. Discussion given in section 6.2 (long or beamy vessel) and 7.1.2 (L/H ratio) explains why the longer ship is not recommended. Furthermore, with this ship length, a coupling train with a standard 77 m barge would be shorter than 185m.

• ***Height (H)* – 3.1 m**.: Freeboard (F) of 0.6 m and safety clearance of 1000 mm (i.e. hatch coaming height of at least 400 mm) is suggested for the vessels of type C (open hold vessels).

Nevertheless, taking into account some recent disasters due to insufficient safety clearance **F = 0.6 m and a coaming height of 1.1 m** is suggested, which is more than required by the rules. Besides, H=3.1 also satisfies GL suggestion for L/35.

• ***Ship form* – should be optimised for low resistance navigation in shallow water**. The form should be relatively full (both CB and CP around 0.9), with full fore- and after-body providing substantial buoyancy (hence allowing larger payload) at low draughts. This, however, will inevitably increase resistance. After body is strongly influenced by propeller diameter and proposer type (twin rudder-propellers of relatively small diameter are imagined here). Ship form should mirror weight distribution (accommodation in the front, engines at the stern) which should reduce the trim of partly loaded ship. The above-water bow form should be adapted for pushing (coupling train formation). Note, however, that hull form optimization with the purpose to reduce resistance requires model testing.

• ***Ship weight* – should be reduced by around 10% compared to conventional designs** by applying state-of-the-art technologies, probably high tensile steel for the hull structure, SPS or aluminium for superstructure. Capital weight savings, however, should not be expected, but overall weight savings within the classical steel-building approach might be obtained (see Section 7.1.2). Although somewhat opposite to the weight savings, ballasting is often necessary, so ballast tanks should be considered too.

• ***Propulsion* – two rudder (azimuthing) propellers in nozzles with D≈1.35 m** optimised for both low draught and full draught operation. These may be of-

**a)** Innovative design, for instance **diesel-electric with Azipods**,or**b)** conventional mechanical **"Z drive" rudder propellers**. Both will eliminate the need for rudders and will also enable exceptional maneuvering capabilities. If diesel-electric propulsion is envisaged then an innovative tip-driven proposer might also be considered.

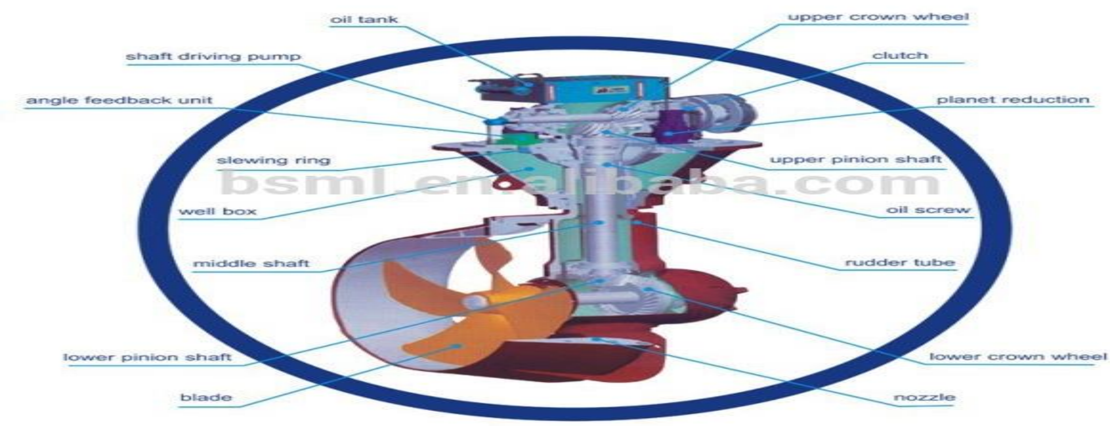


**Figure: Azimuthing Propeller**

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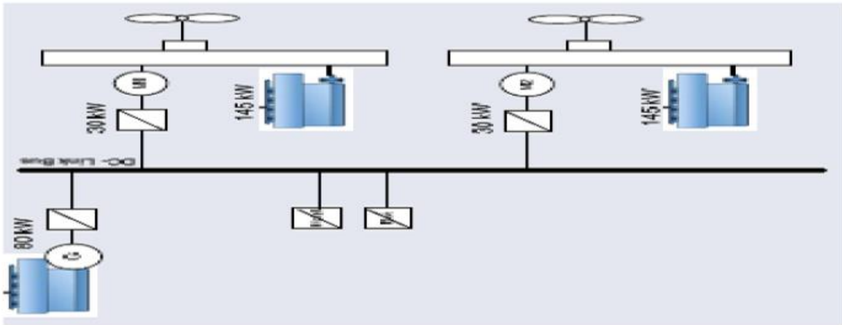


**Figure: Proposed Hybrid Propulsion System**

A **bow thruster of around 250 kW** (with the ability to assist stopping and improve thrust – four-channel) either diesel or electrically driven, should be considered.

• ***Engines*** **– low emission diesel engines satisfying Stage IIIA/Tier 3 norms or better** with relatively high power to weight ratios should be considered. If diesel electric propulsion would be applied (Azipods), then a power of around **4x400 kW** is

suggested; for mechanical rudder propellers around **2x700 kW** or so would be sufficient.

Power is estimated for an assumed speed of 16 km/h, as well as a coupling train formation with one, probably two barges (depending on waterway conditions). Diesel-electric propulsion is ecologically very attractive, but is also more expensive than mechanical transmission. Near zero emission FC or similar (see Section 7.3.5) shouldn't be expected to be seen on IW vessels in next decade or two. Nevertheless, in future diesel-electric sets may be replaced by FC, so electrically driven rudder-propellers (of Azipod type or tip-driven/rim driven) might be regarded as the proposer of the future.

• ***Shore-to-ship-power supply*** (of electricity while in port, often called *cold ironing*) should be considered with the aim to reduce on-board diesel emissions.

• ***Accommodation, wheelhouse and engine room***: All crew premises should be dimensioned a based on six crew members and should be positioned in the bow (the wheelhouse too), while the engines (placed in well insulated spaces) should be at the stern. This enables good visibility (hence safety too), crew comfort (no vibrations and noise) and a well-balanced ship at low draughts.

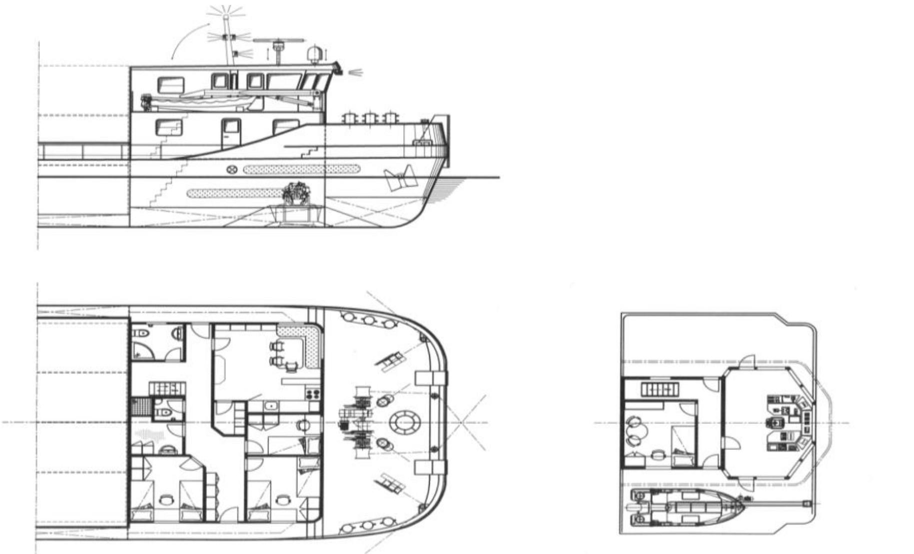

**Figure: Enlarged Bow Design**

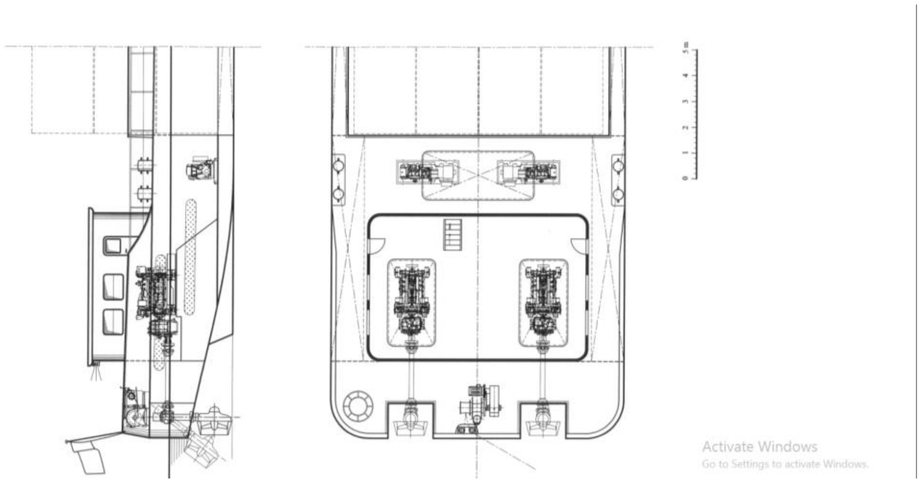


**Figure: Enlarged Stern Design**

***7*. Barge train for transport of bulk cargo**

The main advantage of a push train, or barge transport, compared to self-propelled ship
transport, is that cost-effective navigation with reduced draught with partly loaded barges maybe utilized. Usually it is the draught of a push boat that poses the main problem, as it cannot be reduced below a certain level (the transom and propellers should have designed minimal draught, otherwise they cannot work properly). Conventional push boats with a power of around 2000 kW usually have draught of more than 1.7 to 1.8 m, meaning that this draught is actually a limiting factor. Due to that, pulling technology was never completely abandoned on as towing vessels have lower draught (usually below 1.5 m) and are therefore used during the dry seasons. Consequently, a low draught push boat with a power of around 2000kW would be more than advantageous.

If navigation with a reduced draught would be required, then to substitute for reduced carrying capacity, the number of barges in a convoy might be increased; power needed for pushing this convoy would not increase proportionally; this is the main advantage of push boat technology). Suggested power of around 2000 kW would be sufficient for sailing along the whole Ganges at usual push train speeds with up to six fully loaded barges (with a carrying 1500 to 1600 t each). Tonnage capacity at reduced draught of a barge (77x11x2.8 m) follows:

**T** [m] ~0.5 1.0 1.5 2.0 2.5

***Tonnage*** *[t]* **-** 300-400 700-800 1100-1200 1500-1600

Note that according to the ToR, vessels for bulk cargo and container transport should be suggested. Therefore, a self-propelled vessel was designed particularly for container transport, and a barge train was designed for bulk cargo, although discussions that follow would be the same for other cargo (general cargo, containers etc.), the only limitation being the draught of barges and of a push boat.

8.2.1. Proposed features of a push boat concept

• ***Draught (T)* – 1.4 m maximum.** Larger draught would certainly be desirable from a
Hydrodynamic point of view, but if there is a need to push a convoy at extremely low waters, then 1.4 m is probably the maximum allowable draught. With the above mentioned draught, a propeller in a nozzle with a diameter of 1.5 m could accept power of up to 700 kW, making a three-propeller installation feasible. Furthermore, a standard barge with a draught of 1.5 m will carry a bit less than 800 t, which is approximately half of the carrying capacity of a fully loaded barge at 2.5 m. It is a discussible subject, but sailing at a lower draught than 1.5 m would probably not be cost-effective.

From this point of view, the push boat's draught of 1.4 m is also justified. Obviously the choice of draught is the most important technical compromise in push boat design.

• ***Triple-screw propulsion:* (skewed) propellers in nozzles with a diameter (D) of 1.5 m,** should be located in a relatively shallow tunnel. A somewhat larger propeller diameter would be allowable (and desirable), but taking into account the limited breadth of 11 m and high-speed diesels, it is believed that 1.5 m would be just sufficient. With an engine power of 700 kW, propeller loading would be 375 kW/$m^2$, which is high, but is still acceptable. Special attention should be paid to the design of tunnels, propellers and a nozzles with the aim to increase ahead and astern thrust and reduce vibrations (model experiments are recommended).

• ***Breadth (B) – 11:*** this is the same as a standard barge. A somewhat larger breadth would not be so harmful, as the push boat is usually pushing a much wider barge
convoy. Even if only one barge is pushed, a somewhat wider push boat (than a barge) would not be so disadvantageous. Barge packing, however, is easier if both the push boat and a barge have the same width. Nevertheless, if draught is limited, then either the length or a width (or both) should substitute the needed buoyancy. Consequently, it was decided to fix the breadth to 11 m.

• ***Length (L)* – of around 30 m**, under the condition there is enough space for all necessary machinery and crew. A somewhat longer vessel (if B and T are fixed) would be acceptable. With L=30 m, the overall length of a convoy of two barges and a push boat would be 2x77+30=184 m.
• ***Height (H)* – 2.5 m** is considered to be minimal for fitting engines and other necessary machine-room equipment below the deck.
• ***Weight*** (dry) is estimated to be 270 t taking into account lightweight engines and other equipment and machinery. A larger value might compromise the draught and therefore then project itself. A fully loaded push boat with fuel and other provisions should be around 350 t (at a level draught of 1.4 m). Weight saving should be considered wherever possible (SPS technology might be employed for the superstructure).
• ***Ship form*:** and particularly the tunnels, is of utmost importance as relatively large power needs to be installed within an extremely shallow draught hull. The transom and propellers should always have a draught of around 1.4 m, while weigh variations (due to fuel consumption) should change the trim and bow draught only. Model experiments are recommended.
• ***Propulsion plant* - Low emission diesel engines of 3 x 700 kW, satisfying Stage IIIA/Tier 3 norms or better** (see Section 7.3.3) with relatively high power to weight ratio should be considered. Transmission of power should be via **conventional horizontal shaft line** and a gearbox (with somewhat higher reduction ratio), see Section 7.2.2. Main engines and gensets should be flexibly mounted to the motor girder to reduce noise and vibrations levels. With installed power of around 2000 kW sailing along the whole Danube with a push train of six fully loaded barges (at T=2.5 m, carrying around 1500 to 1600 t of cargo each) at usual convoy speeds is possible during most of the navigable season. Expected fuel consumption would be around 10t/day.
• ***Shore-to-ship-power supply*** (of electricity while in port, often called *cold ironing*) should be considered with the aim to reduce on-board diesel emissions.
• ***Steering*** – **three fish-tail rudders** located behind propellers and a **gondola type bow thruster** (with electrical motor) of around **300 kW** should be considered.
• ***Provisions* – for max 7 days**, meaning that 70 t (around 85 m3) of fuel should be provided. Nevertheless, although on the Danube it is accustomed to carry relatively large quantities of fuel (often for a round-trip), much smaller quantities and refueling on the way should be considered as overall situation within the New Europe has changed. Carrying smaller quantities of fuel might be a cost-effective measure.0
• **Wheelhouse – with the possibility to be raised** to increase visibility to at least 250m.
• **Electronics** and computerization should be of the latest technology, providing one-man watch operation of the vessel with engine and ship-system monitoring and recording, voyage optimization, etc. Everything else should be as usual on a push boat of this size, intended for navigation. Nevertheless, modern lightweight equipment and materials should be considered wherever possible, as larger weight (displacement, hence draught) than predicted can easily compromise every push boat.

**6.1.** ***General arrangement plan of a push boat concept***

| | | |
|---|---|---|
| **Loa** | m | 30.0 |
| **Boa** | m | 11.0 |
| **H** | m | 2.5 |
| **T** | m | 1.4 |
| **Height above basis line** | m | 6.0 |
| **$P_B$** | kW | 3 x 700 |
| **Bow thruster** | kW | 250-300 |
| **Crew** | | 8 |

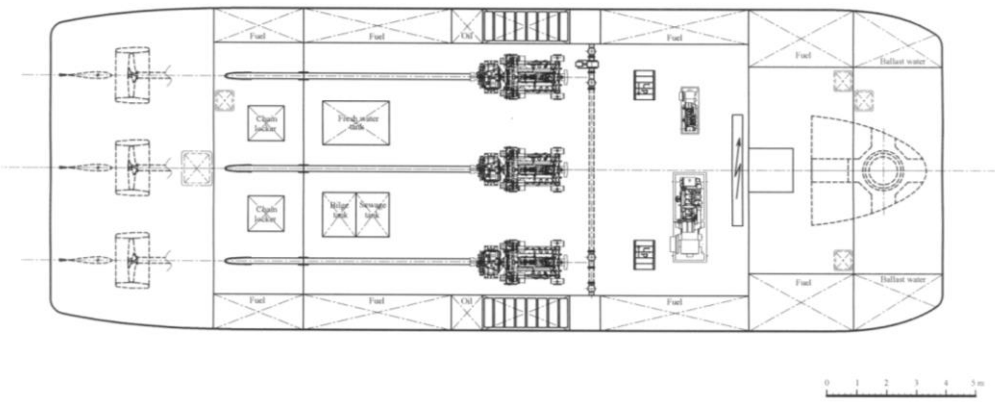

**Figure: General arrangement of Push Boat concept**

Concluding remarks

In order to achieve more efficient and cleaner IWT, contemporary logistics concepts should be applied. Transshipment should be cheap and fast, and the waterborne part of transport should be efficient. Concerning the last item, besides the measures that often do not depend on ship design (crew costs, taxes, loan and fuel costs), the following is necessary -

a) Reduction of total resistance
b) Increase of propulsion efficiency
c) Reduction of fuel consumption
d) Reduction of ship speed (if possible)