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MESSAGE FROM THE CHIEF PATRON

It is my distinct pleasure to extend my warmest greetings as we launch the second issue of the Journal of Engineering and Technology, proudly published by Maritime University Bangladesh. As Vice Chancellor of the university and Chief Patron to this esteemed journal, I take immense pride in witnessing the continued growth and impact of our scholarly endeavors in the fields of engineering and technology.

Our university has always been at the forefront of fostering academic excellence and innovation, and this journal serves as a testament to our commitment to advancing knowledge and addressing global challenges through rigorous research and scholarly inquiry. The articles featured in this issue represent a diverse array of topics and perspectives, reflecting the dedication and expertise of our faculty, researchers, and contributors.

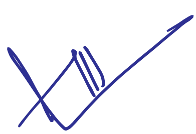
I commend the editorial team for their meticulous efforts in ensuring the quality and relevance of each published work. Their dedication to maintaining the highest standards of academic integrity is commendable and critical to the success of our journal.

As we move forward, I encourage our esteemed faculty, researchers, and students to continue engaging actively with the Journal of Engineering and Technology. Your contributions not only enrich our academic community but also contribute significantly to the advancement of our respective fields and beyond.

I extend my heartfelt appreciation to all authors who have contributed their valuable research, reviewers who have provided insightful feedback, and the editorial team for their unwavering commitment to excellence. Together, we will continue to elevate our university's profile as a hub of innovation and intellectual discourse.

I look forward to the continued success and growth of the Journal of Engineering and Technology and eagerly anticipate the impactful contributions that lie ahead.

Warm regards,



Vice Chancellor and Chief Patron
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Journal of Engineering and Technology

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EDITOR'S NOTE

It is a matter of great honor for me to welcome you to the second issue of the Journal of Engineering and Technology, published annually by the Faculty of Engineering and Technology at Maritime University Bangladesh. As Chief Editor, I am delighted to present this collection of research articles and contributions that showcase the latest advancements in our fields of study.

This journal serves as a vital platform for scholars, researchers, and practitioners to share their innovative ideas and discoveries across various disciplines of engineering and technology. Our mission remains steadfast: to promote high-quality research that contributes to the academic community and addresses real-world challenges.

Since our inaugural issue, we have made significant strides in consolidating our position as a reputable scholarly journal. The second issue builds upon the success of its predecessor, featuring a selection of meticulously reviewed articles that exemplify excellence in research and scholarship. Each submission has undergone rigorous peer review, ensuring that only the highest quality work is presented to our readers.

I extend my sincere gratitude to the authors who have entrusted us with their work, the reviewers whose expertise and dedication uphold our standards, and the editorial team whose commitment ensures the smooth operation of the journal. Your contributions are instrumental in maintaining the academic rigor and integrity of our publication.

Looking ahead, I am excited about the future of our journal. We are committed to expanding our scope, fostering interdisciplinary collaborations, and exploring new avenues for impactful research. I encourage all members of our academic community, both within Maritime University Bangladesh and beyond, to consider the Journal of Engineering and Technology as a platform for sharing your research findings and insights.

Thank you for your continued support and enthusiasm. Together, let us propel the Journal of Engineering and Technology towards greater heights of excellence and innovation.

Warm regards,

Cdre Md Zakirul Islam, (E), ndc, psc, BN
Chief Editor
Dean, Faculty of Engineering and Technology
Maritime University Bangladesh

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INVESTIGATION OF RELATIVE PERFORMANCE OF HIGH-SPEED PLANING VESSELS OF 62, 65-A AND 65-B SERIES

Md. Sadiqul Baree[a]*, Hafizur Rahman Himel[b]

ABSTRACT

High-speed marine vessel design is now recognized as one of the most popular field of naval architecture. Higher speed makes these vessels more efficient and useful for military, economic, or leisure activities. The planing hull is specifically designed to achieve relatively high speed on the water surface. The speed of the vessels operating on the water surface is proportional to its size and installed power. The Savitsky method has been employed here for resistance prediction. This method is well-known as a reliable alternative to CFD hull resistance analysis. Three different planing hull series models (Series 62, Series 65-A, and Series 65-B) have been used to evaluate the performance. MATLAB code has been developed to create a computer program based on Savitsky's method. The program first reads some key parameters such as projected chine length, beam, volumetric displacement, LCG, volumetric Froude number, deadrise angle, and so on, and then calculate hull resistance using Savitsky's empirical planing equation. However, some parameters that are needed in the empirical equations are only available in graphical form, making automation computation challenging. A digital plotting system has been used to extract data from a nomogram. As a result, the value of the wetted length-beam ratio can be calculated directly from the input of initial variables, automating the resistance calculation and removing the need to manually plot secondary variables such as P/b and other coefficients. Furthermore, an equilibrium check for trim angle was performed to verify porpoise stability. Finally, performance of different hull models was evaluated and a relative ranking of the models has been done based on performance.

Keywords: Planing vessels performance; Savitsky’s Method; Series 62; Series 65; MATLAB Code;

1. INTRODUCTION

Naval architects and designers have worked to better understand and improve the design and performance of high-speed marine vessels. High-speed marine vessels are becoming increasingly popular among the world's navies. The hull forms of these vessels are typically chosen to achieve the desired performance and seakeeping characteristics based on the operating environment. Unlike the other two types (Displacement and Semi-Displacement), planing hulls are lifted by hydrodynamic pressure rather than hydrostatic pressure. However, when cruising at low speeds, all three types are considered displacing. Hydrodynamic lift increases in proportion to speed. The buoyant force, on the other hand, decreases as the hull lifts out of the water, resulting in less displaced volume. When the vessel reaches a certain speed, lift becomes the dominant upward force on the hull, and planning begins.

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To evaluate the performance of a high-speed marine vessel, it is usually necessary to review some previously published research papers. Clement [1] investigated the resistance and performance of Series 62 models. Savitsky [2, 4] and J. B. Hadler [3] worked on predicting the performance of planning hulls. The development of the Blount factor [5], which modified the Savitsky method, for better prediction of Series 62 model resistance, is reviewed.

Gerritsma et al. [6] used high-speed model tests to predict the resistance and stability of several planing vessel. D. Clarke et al. [7] evaluated Geritsma et al. method's accuracy and found it adequate for design purposes.

Later, Savitsky created a formula for calculating the resistance of warped planing hulls [8]. S. Brizzolara and F. Serra [9], T. T. O'Shea et al. [10], and C. Judge et al. [11] all compared the Savitsky method to CFD calculations of planing hull resistance. Azim Hosseini et al. [12] analyzed the performance of a hard-chine planing hull using various CFD models. Andi Trimulyono et al. [13] investigated the effect of a double step position on planing hull performance.

The primary goal of this research paper is to assess the resistance thus performance of various models of different series, such as Series 62, 65-A and 65-B, and then draw relative ranking of the models. A computer code is developed in MATLAB to predict the performance during the preliminary design phase.

2. Methodology

The hull resistance was estimated from the following equation:

$$R_T = W \tan\tau + ½ V^2 \lambda b^2 C_{F0} / (\cos\tau \cos\beta) \qquad (1)$$

Where,
W = weight displacement, (KN) = $\rho g \nabla$
∇ = volume of displacement, m^3
τ = trim angle of planing area (degree)
ρ = mass density of water, kg/m^3 = 1.025 kg/m^3
λ = mean wetted length-beam ratio
V = ship velocity, m/s
b = beam of planing surface
C_{F0} = Friction coefficient = $0.075 / (\log R_{nb} – 2)^2$
R_{nb} = Reynolds Number, Considering V_1 & b = $V_1 \lambda b/\nu$
β = angle of deadrise of planing surface (degree)

In the above equation, λ was obtained from nomogram provided by Koelbel [14] on the basis of p/b ratio and speed coefficient, C_V. The following formula was then applied to determine the trim angle, τ.

$$C_{Lb} = \tau^{1.1} (0.0120\sqrt{\lambda} + 0.0055\lambda^{5/2}/C_V^2) \qquad (2)$$

Where,
C_{Lb} = Equivalent flat lift coefficient and was obtained from:

$$C_{Lb} = \frac{\rho g V}{0.5 \rho b^2 V^2} \qquad (3)$$

Effective power of the vessel now estimated from:

$$P_E = R_T * V \qquad (4)$$

To analyze the performance of a planing hull with different hull models, a huge set of data had to be generated to evaluate the performance of different hull models. To get values of these parameters, especially λ, we need to go through the nomogram (Koelbel) manually, which is a cumbersome job. For this reason, the entire procedure of calculating resistance, and intermediate parameters using Savitsky's approach was coded using MATLAB. In this respect, the nomogram (Koelbel) for determining the mean wetted length-beam ratio, λ and trim angle, τ was digitally plotted in MATLAB code using Origin Pro (2019), a plot digitizer software. First, the nomogram image was imported into the software. The curve lines were then created over the nomogram (Koelbel) plot's curves, and data from each curve was extracted individually. This extracted data was then saved in an Excel sheet, and MATLAB code was written to read the Excel sheet data and build a separate digitally viewable Figure. This graphing was then compared to the actual nomogram to ensure total accuracy. The saved data points were used as a source for further computations. The developed automated nomogram is shown below.

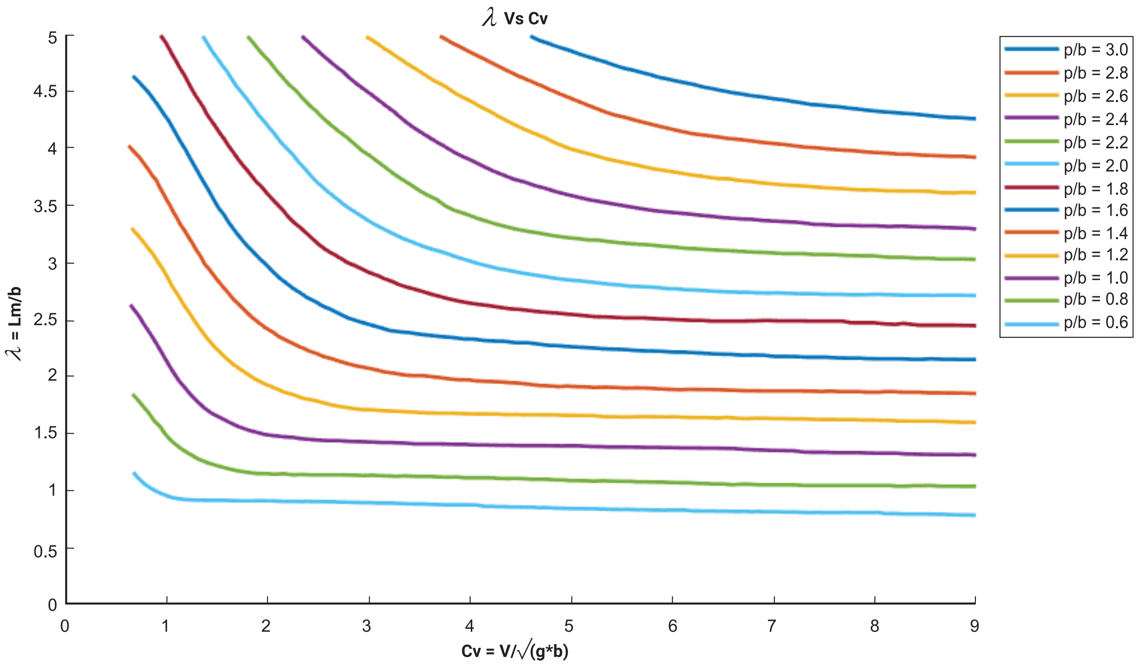

Figure 1: Digital Plotting of Nomogram (Koelbel), Curves for λvs CV.

The above procedure has been shown in the following flow-diagram:

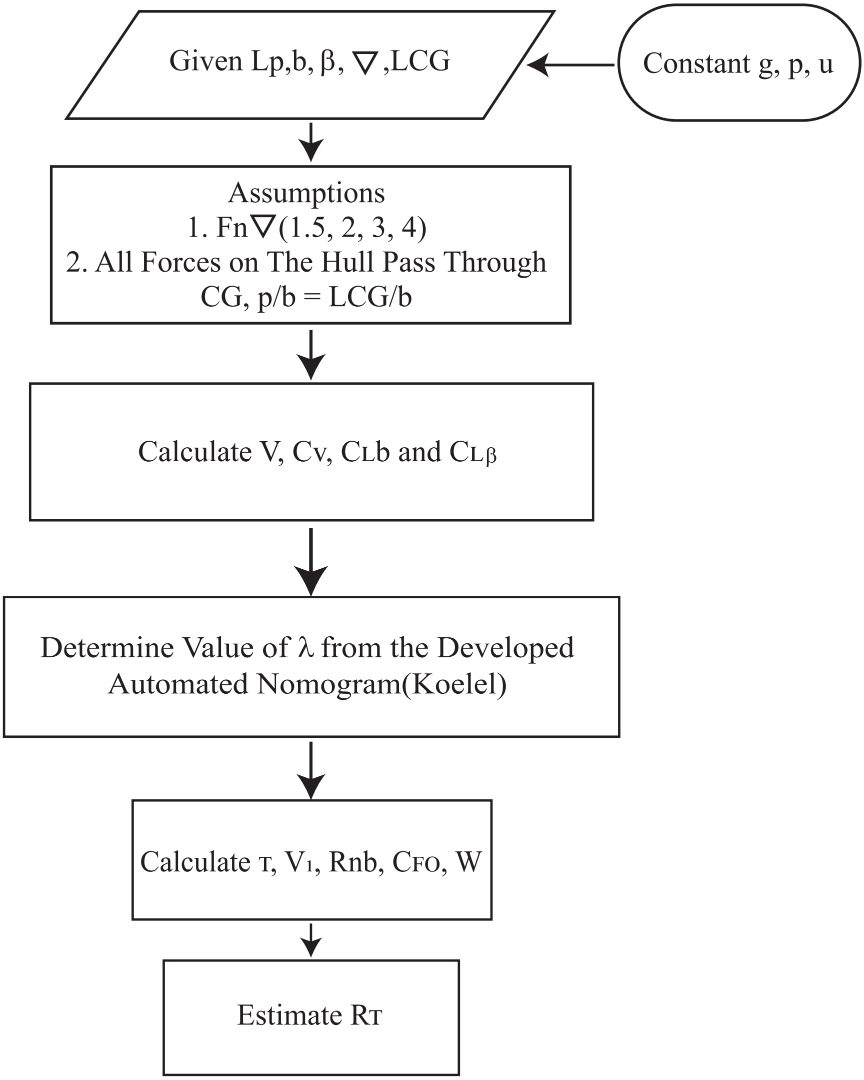

Figure 2: Flow Chart for Planing hull resistance calculation.

3. Validation

In order to validate the procedure mentioned before, results from the developed codes for a hard chine hull boat were compared with the results for the same boat given in the textbook "Principles of Naval Architecture, Second Revision (Volume-2, page-105)", The hard chine hull has the following particulars [14]:

L_P= 25m (82 ft)
b = 7.5m(24.6ft) (maximum chine beam)
β= 15° (deadrise at mid-chine lenth)
∇=90m³ (3175 cu ft) (displacement volume)
LCG = 10m (32.8 ft) from the transom

The computations for mean wetted length-beam ratio, (λ), trim (τ), resistance, (R_T) and effective power, (P_E) for the above boat were carried out at different volumetric Froude number, (Fn_∇) and the results are shown below:

The comparisons are shown in Figures (3 to 6).

From the Figures (3 to 6), it is seen that the errors are very negligible and hence the computed results can be regarded as satisfactory. After verification, the data sets are stored in an Excel sheet for further analysis to evaluate the performance of different hull models of high-speed marine vessels.

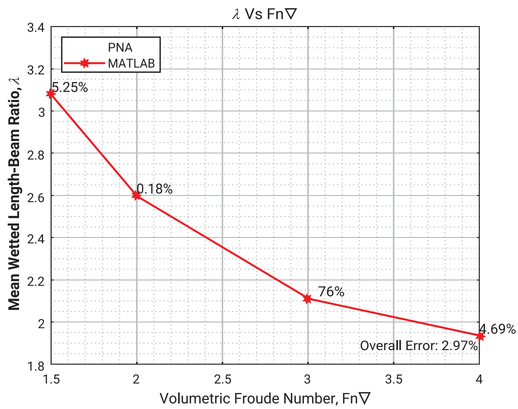

Figure 3: Comparison of Mean Wetted Length-Beam ratio, λ to Volumetric Froude Number, Fn_∇ (PNA with MATLAB Code)

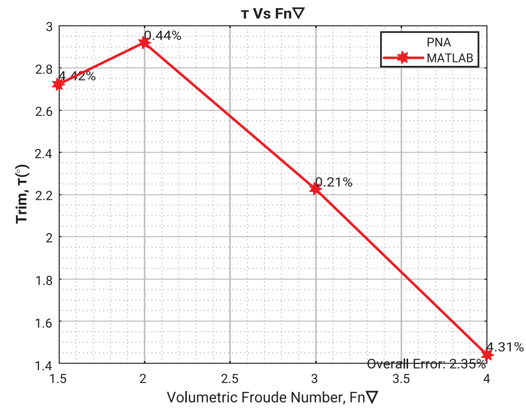

Figure 4: Comparison of Trim, $\tau°$ to Volumetric Froude Number, Fn_∇ (PNA with MATLAB Code)

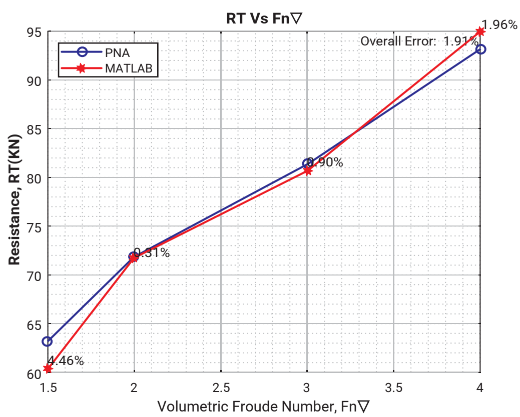

Figure 5: Comparison of Resistance, R_T (KN) to Volumetric Froude Number, Fn_∇ (PNA with MATLAB Code)

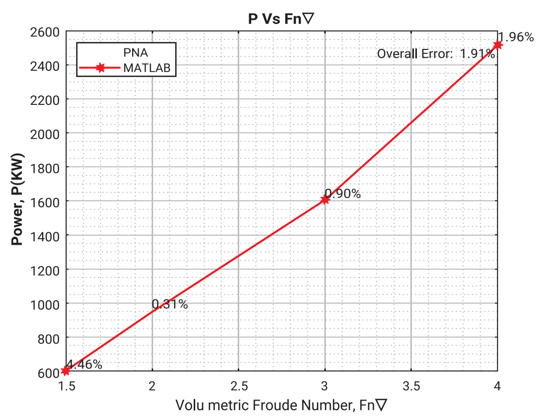

Figure 6: Comparison of Power, P (KW) to Volumetric Froude Number, Fn_∇ (PNA with MATLAB Code)

4. Results and Discussion

Savitsky's method has been employed here for performance prediction for the planing hull Series. Following hull models of Series 62, Series 65-A and Series 65-B were considered. The primary parameters include length, volumetric Froude number, displacement, deadrise angle, LCG, and so on. For computation purpose, 2 models from each of the Series, i.e., 6 models in total are considered for the study. For each model, computations were carried out for three different lengths (25m, 32m and 38m), three different volume displacement (90 m^3, 102 m^3, and 135 m^3), two different deadrise angles (15° and 20°) and four different volumetric Froude numbers (1.5, 2, 3, and 4). The parametric values taken from [14] for the models of each series are shown in Table 1. Here the models have been divided into two sets depending on the value of L_p/B_{Px}. However, it may be noted that all the Figures (7 to 15, 17 to 22 and 29 to 34) are for L_p = 25m and deadrise angle β=15°. The detailed results for all the models including all variations are given in ref. [16].

Table 1: Planing Hull Different Model Particulars.

SET	SERIES	MODEL	L (m)	A (m)	B (m)	L /B	φ (Degree)
A	65-A	5198	2.226	0.769	0.477	4.66	22.1
	65-B	5184	1.872	0.55	0.399	4.69	28.7
	62	4667-1	2.438	1.189	0.596	4.09	13
B	65-A	5251	1.861	0.761	0.564	3.3	16
	65-B	5240	1.872	0.779	0.564	3.32	21.2
	62	4666	1.825	0.903	0.596	3.06	13

4.1. Influence of volumetric Froude Number, Fn∇ on mean wetted length-beam ratio, λ

Figures 7, 9, 11 have been plotted for demonstration of the results for λ vs Fn∇ at three different LCG positions (46%, 50% and 54%) for Set-A.

In a similar way, Figures 8, 10 and 12 have been plotted for Set-B, for λ vs Fn∇ at three different LCG positions like set-A.

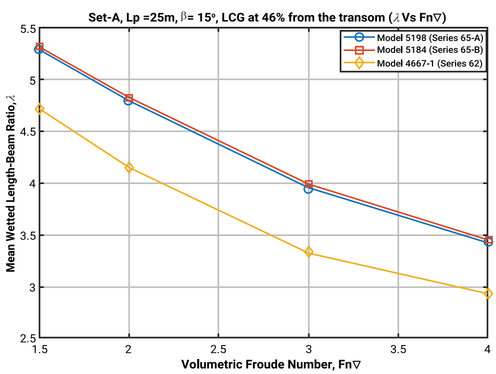

Figure 7: λ vs Fn∇, for Set-A, LCG at 46% from the transom

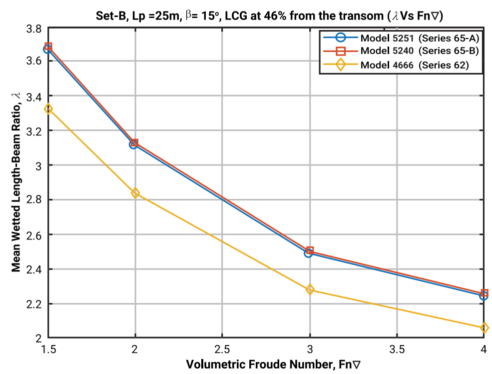

Figure 8: λ vs Fn∇, for Set-B, LCG at 46% from the transom

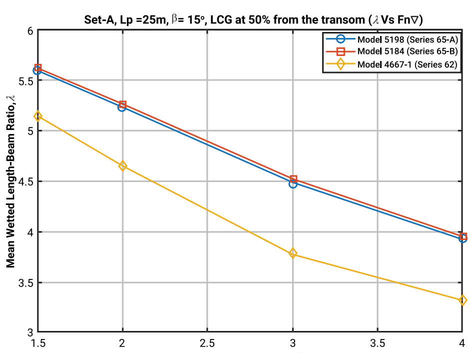

Figure 9: λ vs Fn∇, for Set-A, LCG at 50% from the transom

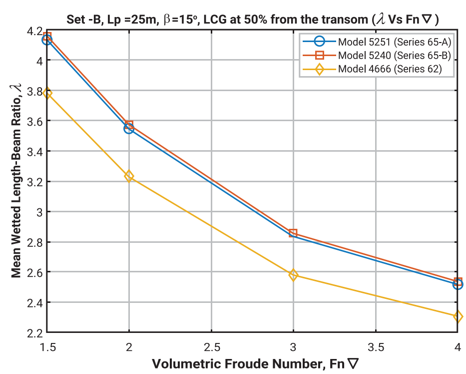

Figure 10: λ vs Fn∇, for Set-B, LCG at 50% from the transom

From Figures 7, 9 and 11, it is seen that with the increase of Fn_∇, the λ decreases for all the three positions of LCG for all Models. However, results of λ for series 65-A and series 65-B are very close to each other and varies from 5.3 to 3.5 for LCG position of 46%, from 5.6 to 3.9 for LCG position of 50% and from 5.8 to 4.4 for LCG position of 54%, while series 62 of set-A has reasonably less values of λ and varies from 4.7 to 2.9 for LCG position of 46%, 5.2 to 3.3 for LCG position of 50% and 5.5 to 3.7 for LCG position of 54%. From Figures 8, 10 and 12, similar trends can be seen in set-B models, where set-B of series 62 has considerably less values of λ compared to series 65-A and 65-B and varies approximately from 3.3 to 2.1 for LCG position of 46%, from 3.8 to 2.3 for LCG position of 50% and from 4.2 to 2.51 for LCG position of 54%.

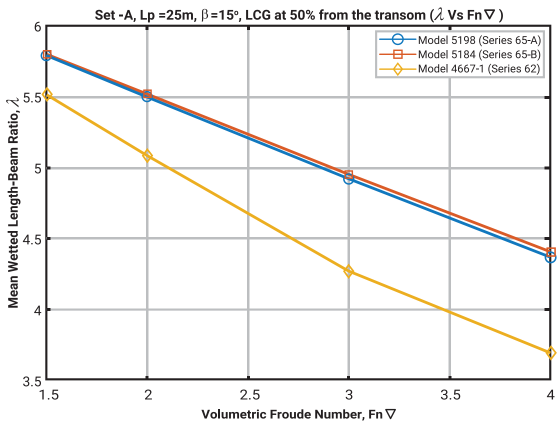

Figure 11: λ vs Fn_∇, for Set-A, LCG at 54% from the transom

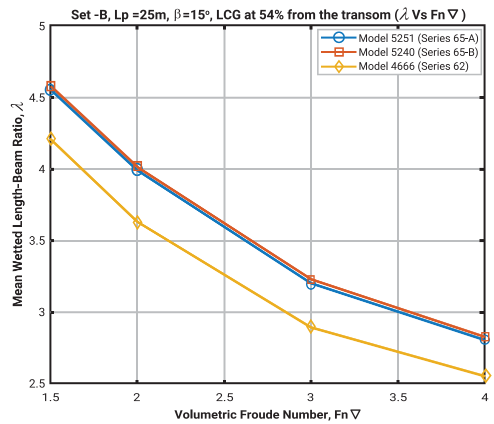

Figure 12: λ vs Fn_∇, for Set-B, LCG at 54% from the transom

4.2. Influence of LCG on λ

In order to show the influence of LCG on λ, Figure 13 has been prepared for series 62 for a particular value of Fn_∇ = 3 for set-A and set-B. From this, it is seen that with the increase of LCG, the value of λ increases. However, in case of set-A, the value of λ are greater than that of set-B.

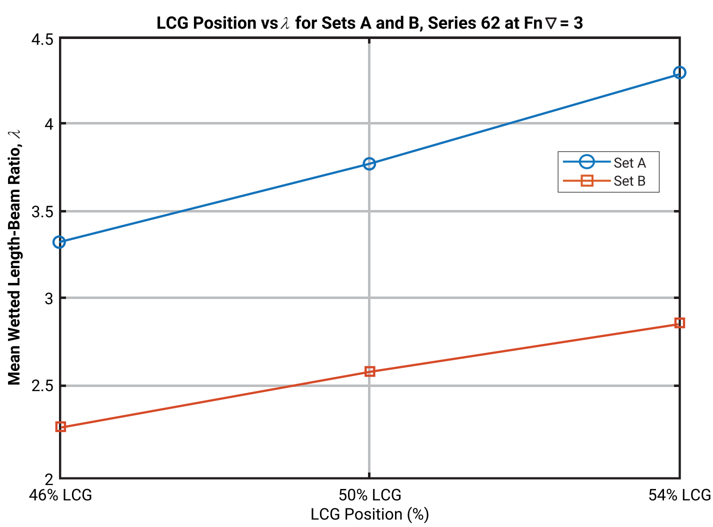

Figure 13: LCG position (%) vs λ for set-A and set-B, Series 62 at Fn_∇ = 3

4.3. Influence of L_P on R_T/W at different deadrise angle, β and LCG positions

Figures 14, 15 and 16 have been prepared to show the influence of L_P, on resistance per weight displacement, R_T/W at two different deadrise angle, β for different positions of LCG (46%, 50% and 54%). It may be noted that all these figures (14, 15 and 16) are for series 62, model (4667-1) and $Fn_\nabla = 4$. It is seen that, with the increase of projected chine length, L_P, values of resistance per weight displacement also increases. Detailed results for other models including all variations are given in ref. [16].

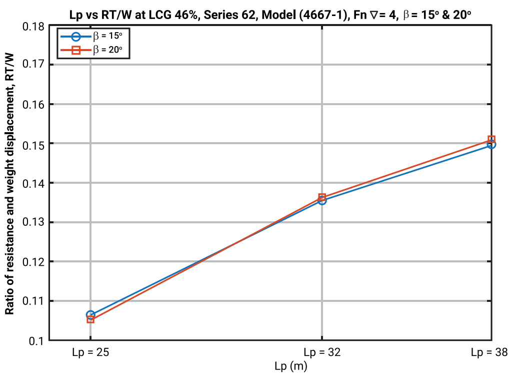

Figure 14: L_P vs R_T/W at LCG 46%, Series 62, Model (4667-1), $Fn_\nabla = 4$, β = 15° & 20°

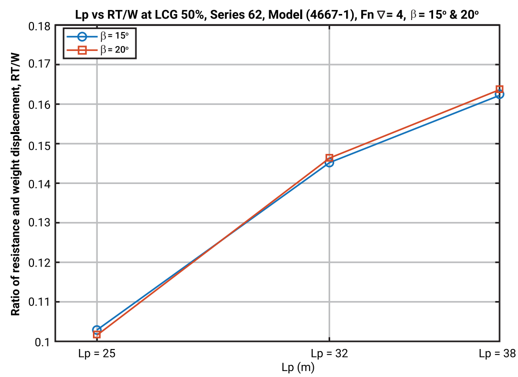

Figure 15: L_P vs R_T/W at LCG 50%, Series 62, Model (4667-1), $Fn_\nabla = 4$, β = 15° & 20°

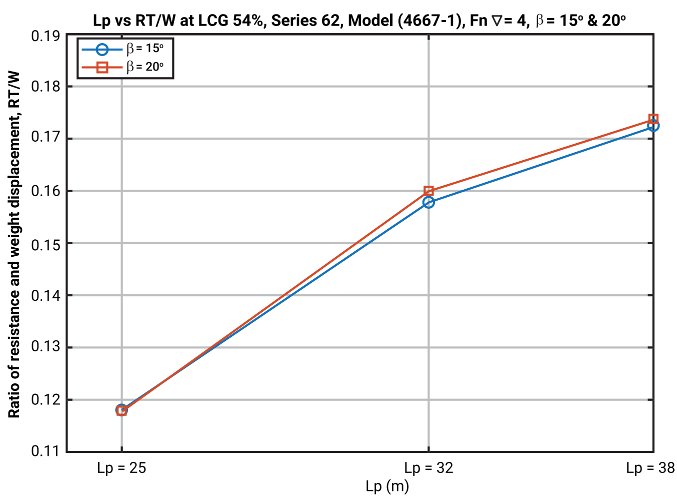

Figure 16: L_P vs R_T/W at LCG 54%, Series 62, Model (4667-1), $Fn_\nabla = 4$, β = 15° & 20°

4.4. Influence of Fn_∇ on R_T/W

Now in order to examine the influence of Fn_∇ on the R_T/W, Figures 17, 19 and 21 should be studied for set-A, while Figures 18, 20 and 22 are for set-B. From these figures, it is seen that, with the increase of Fn_∇, R_T/W increases, irrespective of LCG positions and this is true for all the models that are considered in the study.

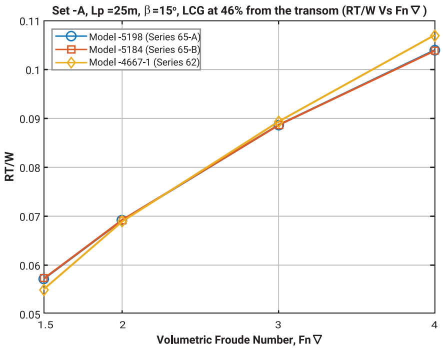

Figure 17: R_T/W vs Fn_∇, Set-A Models, LCG 46% from the transom

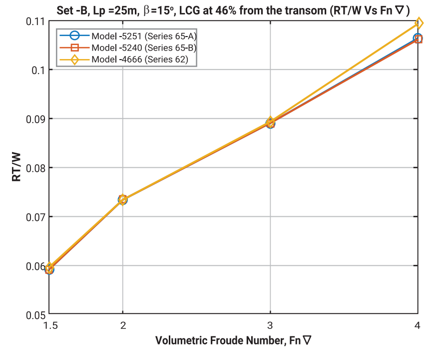

Figure 18: R_T/W vs Fn_∇, Set-B Models, LCG 46% from the transom

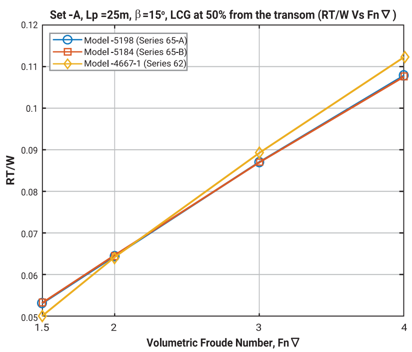

Figure 19: R_T/W vs Fn_∇, Set-A Models, LCG at 50% from the transom

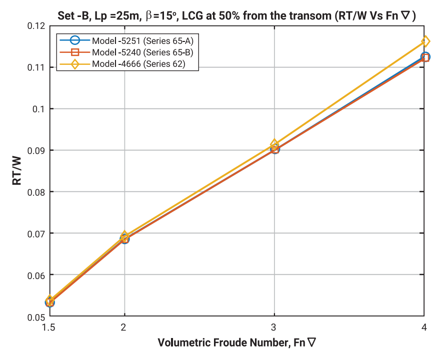

Figure 20: R_T/W vs Fn_∇, Set-B Models, LCG at 50% from the transom

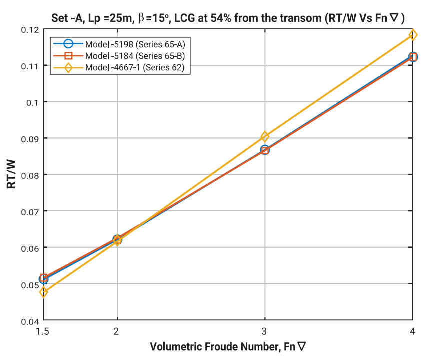

Figure 21: R_T/W vs Fn_∇, Set-A Models, LCG 54% from the transom

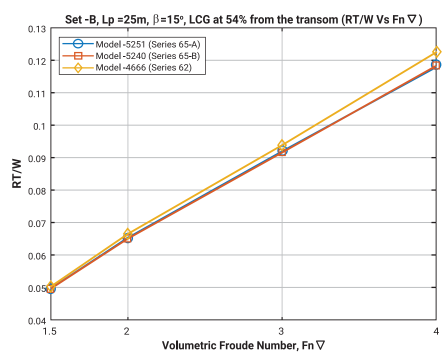

Figure 22: R_T/W vs Fn_∇, Set-B Models, LCG 54% from the transom

4.5. Relative Performance

In order to assess the relative performance of different models, Figures 17 to 22 may be studied again. As mentioned before, with the increase of Fn_∇, R_T/W increases for all the models that are considered in the study. However, from Figures 17, 19 and 21, it is seen that for set-A models, at lower volumetric Froude numbers, approximately (1.5 to 2.25), the values of R_T/W are less for series 62 than that for series 65-A and series 65-B, while at higher volumetric Froude numbers, approximately (2.5 to 4), the values of R_T/W are more for series 62 than that for series 65-A and series 65-B, irrespective of LCG positions.

On the other hand, for set-B models, it is seen from Figures 18, 20 and 22, that at lower volumetric Froude number, approximately (1.5 to 2.25), the value of R_T/W remains very much close for all three series (62, 65-A and 65-B). However, at higher volumetric Froude number, approximately (3 to 4), the values of R_T/W are more for series 62 than that for series 65-A and series 65-B, irrespective of LCG positions.

Among all the models that are considered here, Series 62 models [Model 4667-1 and Model 4666] of set-A, irrespective of LCG positions, show less value of R_T/W, thus more efficient in the range of lower volumetric Froude number (1.5 to 2.25). But if the hulls are designed to operate in the higher range of volumetric Froude number (2.25 to 4), other models of the series (65-A and 65-B) show less value of R_T/W, thus more efficient, irrespective of LCG positions.

4.6. Digitization of Porpoising Limits Graph

Furthermore, an equilibrium check for trim angle was performed to verify porpoise stability. Porpoising is defined as the sustained or increasing amplitude oscillations of a craft in pitch and heave while lanning on smooth water. It may, however, cause structural damage to a high-speed lanning hull if the motions become so severe that the hull is thrown completely out of the water. Day et al. [15] created a graph that depicted the relationship between trim angle and lift coefficient, which defined the start of porpoising. This graph of Day et al. [15], is reproduced here in Figure 23.

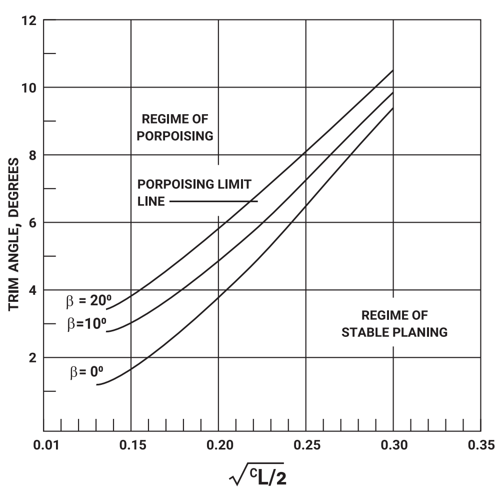

Figure 23: Porpoising Limits for Planing Hull at Different Deadrise Angle.

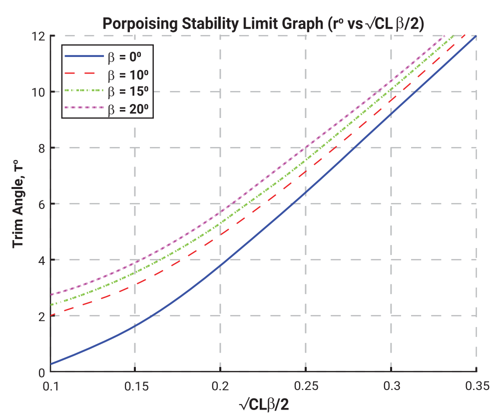

Figure 24: Developed Digitize Graph for Porpoising Limits at Different Deadrise Angle.

4.7 Development of Digitized Graph and Equation for Porpoising Limits

For quick assessment of porpoise stability, initially data were extracted from Figure 23, using graph digitization software. MATLAB code was then developed and using these extracted values, graphs were generated as shown in Figure 24. The accuracy of the graphs was checked and a further division of the graphs of Figure 24, are shown in Figures 25 to 28. From these graphs, equations were also developed using 3rd degree polynomials. These equations are shown in Table 2.

$$Y = ax^3 + bx^2 + cx + d$$

Where, $x = \sqrt{C_{L\beta}/2}$ and $y = \tau°$ (max allowable trim angle)

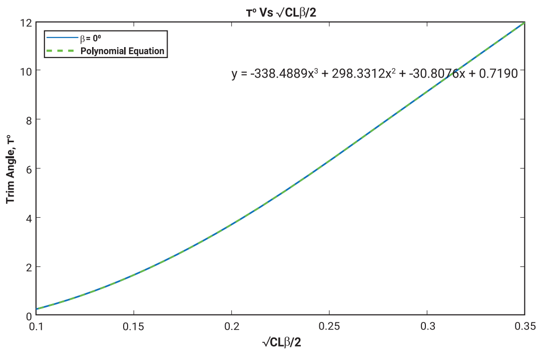

Figure 25: Porpoising limits for planing hull, for β=0°

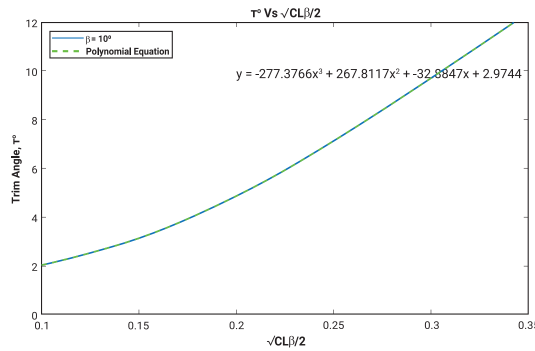

Figure 26: Porpoising limits for planing hull, for β=10°

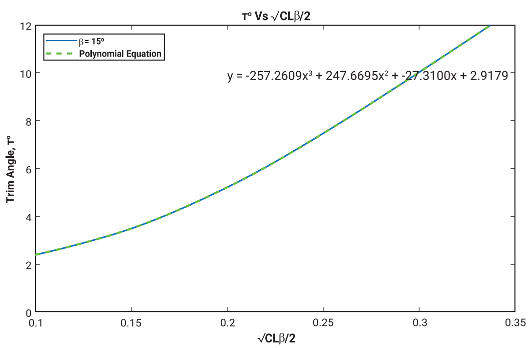

Figure 27: Porpoising limits for planing hull, for β=15°

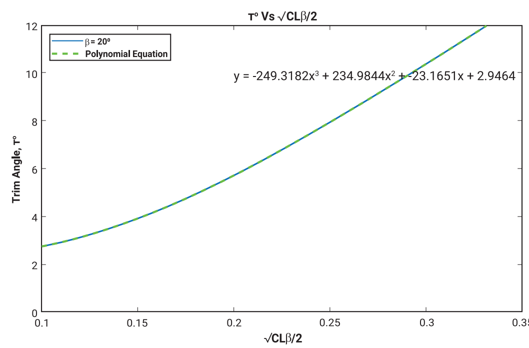

Figure 28: Porpoising limits for planing hulls, for β=20°

Table 2: Porpoising Limit checking polynomial Equation.

Deadrise angle, β°	Equation for Maximum Trim Angle	R^2
0	$-338.4889x^3 + 298.3312x^2 + (-30.8076x) + 0.7190$	1
10	$-277.3766x^3 + 267.8117x^2 + (-32.8847x) + 2.9744$	1
15	$-257.2609x^3 + 247.6695x^2 + (-27.3100x) + 2.9179$	1
20	$-249.3182x^3 + 234.9844x^2 + (-23.1651x) + 2.9464$	1

4.8. Porpoising Stability Limits Check for Models of Different Series

In order to check the porpoise stability, Figures 29 to 34 have been prepared. These Figures show the curves for maximum allowable limit of trim angle as per automated curves generated from Day et al. [15] and curves of the estimated trim angle for the present models taken for the study. It may be noted that various values of trim angles for the models were determined from previous computations using the Koelbel nomogram and equation (2) and (3) as mentioned in the methodology in section 2. Further it may be noted that estimated trim angles are for four different volumetric Froude number (1.5, 2, 3 and 4) and three different LCG positions (46%, 50% and 54%). As can be seen, LCG positions have significant effect on trim. From Figures 29 to 34, it can be seen that, the computed trims, τ° are found to be below the range of maximum allowable porpoising limits for all the models that have been taken for the study. Trims are found maximum when positions of LCG are at 46% and minimum at LCG position of 54%.

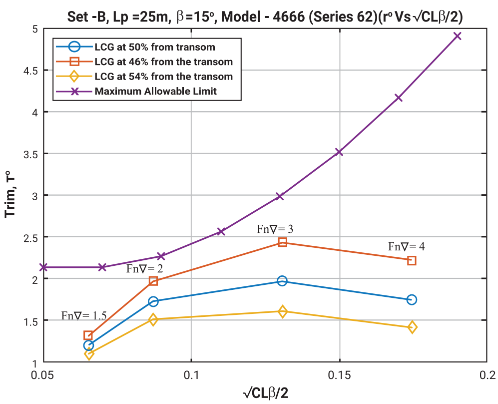

Figure 29: τ° vs $\sqrt{C_{L\beta}}/2$, Model 4666 for different LCG Position

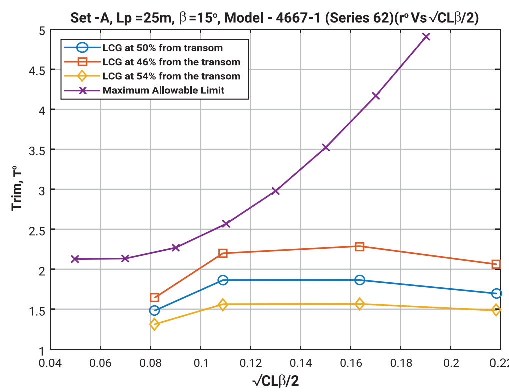

Figure 30: τ° vs $\sqrt{C_{L\beta}}/2$, Model 4667-1 for different LCG Position

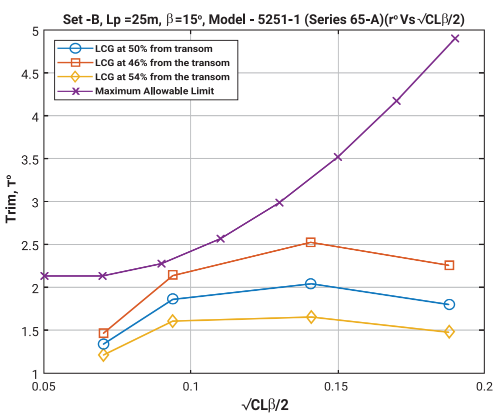

Figure 31: τ° vs $\sqrt{C_{L\beta}}/2$, Model 5251 for different LCG Position

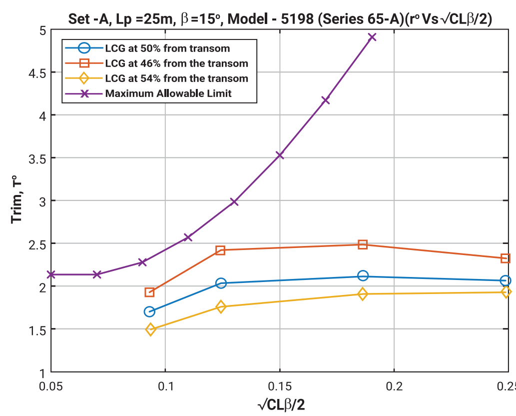

Figure 32: τ° vs $\sqrt{C_{L\beta}}/2$, Model 5198 for different LCG Position

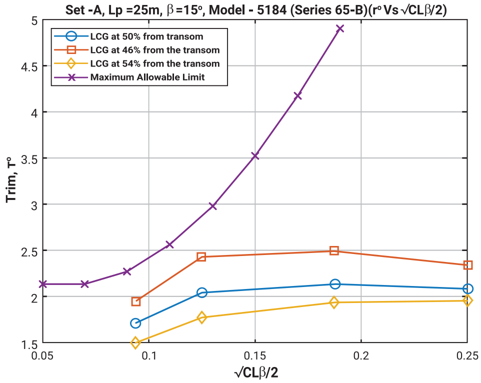

Figure 33: τ° vs $\sqrt{C_{L\beta}}/2$, Model 5184 for different LCG Position

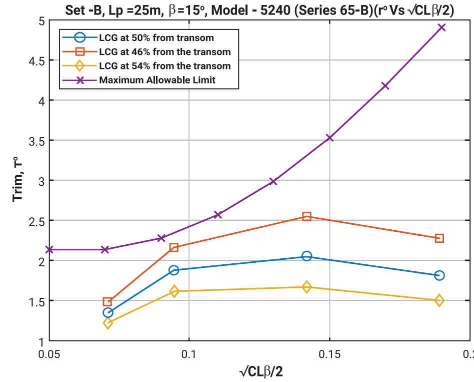

Figure 34: τ° vs $\sqrt{C_{L\beta}}/2$, Model 5240 for different LCG Position

From this study, trim angles for different LCG positions have been found to be smaller than the maximum allowable trim angles for porpoising limit stability. As a result, the porpoise stability of high-speed marine vessels with various hull forms that have been taken for study are found satisfactory.

4.9. Forming a Table of Ranking of Different Series

Finally, on the basis of R_T/W and porpoise stability, a table of ranking for different series can be formed for different range of Fn_∇. The ranking has been made by designating numbers 1 and 2 in different groups, and is shown in Table 3 below:

Table 3: Table of Ranking of Different Series

Range of Fn_∇			
1.5 - 2	**2 - 3**	**2 - 4**	**3 - 4**
1. Series 62 2. Series 65-A and 65-B	1. Series 62, Series 65-A and 65-B	1. Series 65-A and 65-B 2. Series 62	1. Series 65-A and 65-B 2. Series 62
Condition: Applicable for all LCG positions (46%, 50% and 54%).	***Condition:*** Applicable for LCG position of 46%.	***Condition:*** Applicable for LCG positions of 50% and above.	***Condition:*** Applicable for all LCG positions (46%, 50% and 54%).

5. Conclusions

A computer program was developed based on MATLAB code and the Savitsky method for prediction of total resistance. Graph digitization software was used to automate the Koelbel nomogram and digitize the porpoising stability limit. This has simplified graphical data handling, with accuracy. This approach of evaluation of high-speed hull models (Series 62, 65-A, and 65-B) is expected to be useful for better naval architecture design decisions. Influences of several parameters have been studied. Assessing hull performance and ranking them yields valuable insights. Useful conclusions can be drawn as follows:

I. λ decreases with the increase of Fn_∇ for all models. Series 62 models have the minimum values of λ with respect to other two series.

II. With the increase of [redacted]

Parameter	Meaning	Formula
Fn_∇	Volumetric Froude Number	$\nabla/\sqrt{(g*\nabla^{1/3})}$
p/b	Center of Pressure Forward of Transom to Beam Ratio	LCG/b
C_L	Lift Coefficient	-----
V_1	Average Bottom Velocity, m/s	$V_1 = V(1 - \frac{0.0120\tau^{1.1}}{\sqrt{\lambda} Cos\, \tau})^{1/2}$
R_{nb}	Reynolds Number, Considering V_1 & b	$V_1\lambda b/\nu = V_1 * Lm / \nu$
Δ	Displacement in tons	-----

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HYDRODYNAMIC PERFORMANCE ANALYSIS OF THE KP505 PROPELLER IN OPEN WATER: A COMPUTATIONAL APPROACH

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ABSTRACT

Marine vessels depend on propellers to create the necessary thrust force for propulsion. The design and analysis of the propeller's hydrodynamic performance are crucial for optimizing marine operations. The marine propeller KP505 is a propeller design that has comprehensive experimental data available. This study investigates the hydrodynamic analysis of the KP505 propeller's performance in open water circumstances using computational fluid dynamics (CFD) simulations. The NMRI model of the KP505 propeller is utilized for analysis, and the numerical simulation results are compared with the NMRI test results of the KP505 propeller in open water. The propeller performance in open water was analyzed by simulations using the RANS model. The study utilizes simulations and analysis to assess various hydrodynamic parameters along the propeller blades, including thrust and torque coefficients, static and dynamic pressure distribution, and flow patterns. The disparity between the experimental and numerical values for thrust coefficient (K_T) and torque coefficient (K_Q) is minimal. The percentage differences (ε %) display a limited range, ranging from -4.81% to 6.61%. This suggests a positive agreement between the Experimental and Numerical results. This research enhances our comprehension of the hydrodynamics of the KP505 propeller and provides useful insights for improving marine propulsion systems.

Keywords: Propeller; Thrust; Torque; Hydrodynamic performance; Computational fluid dynamics

1. INTRODUCTION

Propellers serve as essential elements in marine propulsion systems, holding a vital role in ensuring the effective functionality of various watercraft, ranging from small recreational boats to large ocean vessels. A thorough comprehension of the hydrodynamic characteristics of propellers is imperative for optimizing their design, improving performance, and guaranteeing safe and dependable operation. The efficiency of propulsion systems directly affects operational expenses for maritime companies. Factors such as design and performance significantly impact fuel consumption, maintenance requirements, and overall operational effectiveness. Additionally, ship propulsion carries notable environmental implications, particularly concerning emissions and fuel usage. As the shipping sector aims to diminish its environmental impact and adhere to increasingly rigorous environmental standards, the advancement of cleaner and more efficient propulsion technologies becomes imperative.

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Because of the extensive range of commercial CFD software choices and the progress in computing capabilities, namely High-Performance Computations, CFD has become a highly dependable and efficient method for tackling flow issues in various industrial sectors. Over the past two decades, Computational Fluid Dynamics (CFD) has made considerable progress in ship hydrodynamics, particularly in ship propulsion [1]. KP505 was specifically engineered by the Korea Research Institute of Ships and Ocean Engineering (KRISO) for the exclusive purpose of being utilized in the KRISO Container Ship (KCS). In this research, the numerical simulation represents the real-world scenario of the propeller and its characteristics in open water. The findings of this study are expected to contribute significantly to the understanding of the hydrodynamic behavior of the KP505 propeller in open water conditions. By providing detailed insights into its performance characteristics, the research aids propeller designers, naval architects, and marine engineers in optimizing propulsion systems for various marine applications. Moreover, the computational approach adopted in this study offers a cost-effective and efficient alternative to experimental testing, thereby facilitating the design process and reducing development time and costs.

1.1 Literature review

Computational fluid dynamics (CFD) simulations were used to analyze the hydrodynamic performance of the KP505 propeller under open water conditions. The simulations examined the thrust and torque coefficients, along with the propeller's efficiency [2], [3]. Various findings indicated that the efficiency of the propeller is influenced by several aspects, including the existence of a pre-swirl stator, cavitation, and scale effects. The augmentation in blade quantity from 3 to 5 led to an augmentation in thrust and torque coefficients, while simultaneously causing a reduction in efficiency [4]. The simulations also conducted a comparison of several meshing procedures and determined that they had a significant impact on the propeller's performance, specifically in relation to thrust and torque [5]. The study examined the performance of propellers in sinusoidal pitch motion with constant tilt angles and concluded that the motion of the ship in waves had an impact on the propulsion performance of the propeller [6]. The computational fluid dynamics (CFD) simulations yielded useful insights into the hydrodynamic characteristics of the KP505 propeller under open water circumstances.

1.2 Research gap

Despite the advancements in computational methods for propeller analysis, there remains a need for comprehensive studies focusing on specific propeller designs under various operating conditions. The KP505 propeller, although widely used in marine applications, lacks detailed computational analysis in open water conditions. Therefore, the primary research problem addressed in this study is to conduct a thorough hydrodynamic analysis of the KP505 propeller in open water using computational techniques.

Existing research might provide overall thrust and torque values, but a deeper understanding of the pressure distribution and flow patterns around the blades is often missing. This study will use CFD to visualize and analyze these details, offering insights into the mechanisms behind the propeller's performance.

1.3 Objectives

The main aim of this study article is to examine the fundamental hydrodynamic factors related to the KP505 propeller's performance in open water circumstances. The study's specific objective is to analyze the propeller's thrust and torque coefficients, which are essential measures of its performance and efficiency. Furthermore, the research aims to analyze the pressure and velocity distributions surrounding the propeller blades, offering valuable insights into the fluid dynamics and flow patterns produced by the propeller.

1.4 Scope of the Study

This study provides in-depth insights into the hydrodynamic performance of the KP505 propeller, which can enhance the design, efficiency, and operational reliability of marine vessels. The detailed computational fluid dynamics (CFD) analysis offers a comprehensive understanding of the flow dynamics around the KP505 propeller, including thrust, torque, and efficiency metrics. These insights can guide the optimization of propeller designs, leading to the development of more efficient and effective propulsion systems. By incorporating the findings from this study, engineers can design propellers that maximize performance while minimizing fuel consumption and emissions, contributing to more sustainable maritime operations.

2. Governing Equations

The Reynolds averaged Navier Stokes (RANS) equations, along with the continuity equation, are used in a three-dimensional computational framework to model the flow of an incompressible fluid. These equations can be expressed in tensor notation as indicated below:

$$\frac{\partial u_i}{\partial x_i} = 0$$

$$\frac{\partial}{\partial t}(\rho u_i) + \frac{\partial}{\partial x_i}(\rho u_i u_j) = -\frac{\partial p}{\partial x_i} + \frac{\partial}{\partial x_j}\left[\mu\left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i}\right)\right] + \frac{\partial}{\partial x_j}\left(-\rho\overline{u_i' u_j'}\right) \tag{1}$$

The variables x_i represent the Cartesian coordinates, u_i represent the velocity components, and p, ρ, and μ represent the static pressure, density, and molecular viscosity, respectively. The quantity $\rho\overline{u_i' u_j'}$ represents the Reynolds stress. In order to solve the governing equation, it is necessary to represent the Reynolds stress using a suitable turbulence model. To solve these equations, a turbulence model is necessary to represent the Reynolds stress. In this study, the SST (Shear Stress Transport) k-ω model is employed, as proposed by [7]. The governing equations are solved using a second-order discretization method for both time and space. The pressure-velocity coupling is achieved using the SIMPLE (Semi-Implicit Method for Pressure-Linked Equations) method.

The efficiency and performance of a propeller can be evaluated based on its behavior in undisturbed, uniform flows under constant loads [8]. The thrust (T) and torque (Q) can be mathematically represented using dimensionless coefficients.

$$K_T = \frac{T}{\rho n^2 D^4} \tag{2}$$

$$K_Q = \frac{Q}{\rho n^2 D^5} \tag{3}$$

These coefficients, K_T and K_Q, are determined by the propeller's diameter (D), water density (ρ), and rotations per second (n), as well as the advance coefficient (J), which quantifies the ratio of forward velocity (V_A) to rotational speed and diameter.

$$J = \frac{V_A}{nD} \tag{4}$$

The propeller's open water efficiency, denoted as η_0, is defined as the ratio of thrust coefficient (K_T) to torque coefficient (K_Q), normalized by J/2π.

$$\eta_o = \frac{K_T}{K_Q}\frac{J}{2\pi} \tag{5}$$

3. Methodology

The research methodology is depicted as a sequential process comprising several key stages **(Figure 1)**. These stages include making preliminary assumptions for the analysis, creating a model of the system, conducting an in-depth analysis of the system, and drawing conclusions based on the findings.

Furthermore, the governing equations and geometric characteristics of propeller under analysis are thoroughly elaborated upon in subsequent sections of this portion.

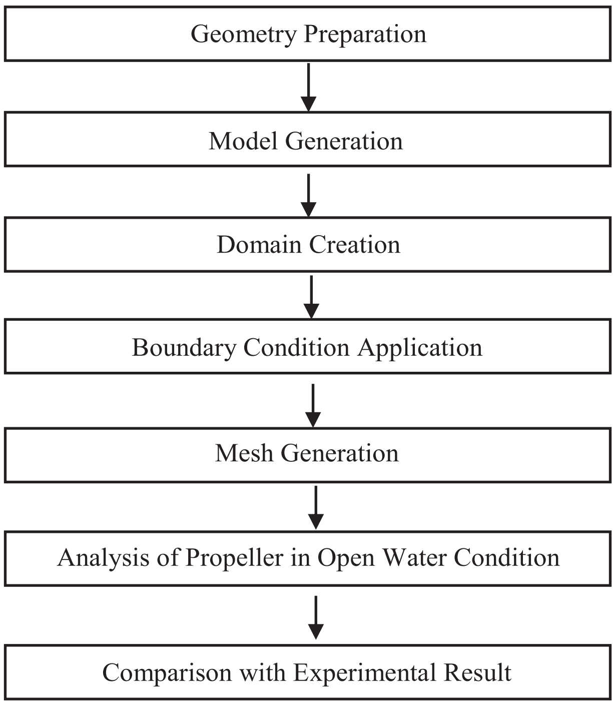

Figure 1: Methodology Flowchart of the Research.

4. Geometry Preparation

The hydrodynamic performance of a propeller, specifically the KP 505 model designed for use with the KCS hull as depicted in **Figure 2**, is analyzed in this study. The National Maritime Research Institute (NMRI), Tokyo, developed a scaled model at a ratio of 75.5 for experimentation purposes. This paper utilizes the NMRI model to examine the hydrodynamic characteristics of the KP505 propeller in open water through computational fluid dynamics (CFD) simulations conducted with ANSYS Fluent software. The obtained results are then compared with NMRI model test results for the KP505 propeller. **Figure 3** illustrates the geometry of the KP505 propeller model from two different angles, while **Table 1** provides details regarding the principal particulars of KP505 propeller model. Additionally, **Figure 4** presents a sketch depicting the geometry and dimensions of a single blade of the KP505 propeller.

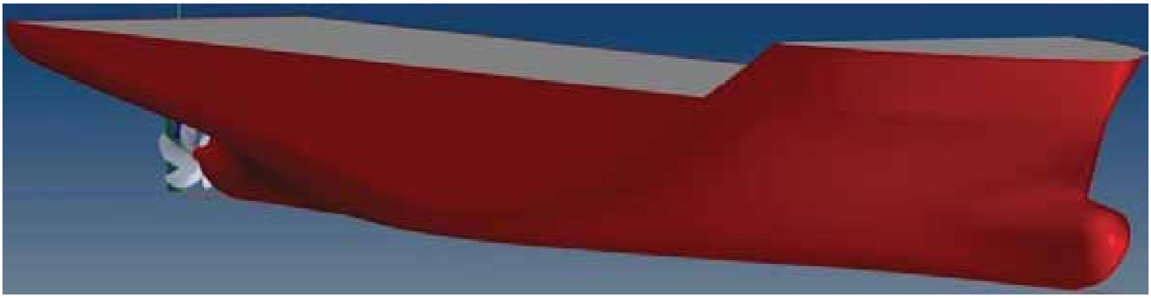

Figure 2: KCS Hull with KP505 Propeller [9].

Table 1: Principal Particulars of KP505 Propeller

Model	NMRI
Scale ratio	75.5
Hub ratio	0.18
Expanded area ratio	0.8
Propeller Type	Fixed Pitch
Diameter (m)	0.105
No. of blades	5
P/D (0.7R)	0.997
Rotation	Right hand

Figure 3: KP505 Propeller Model.

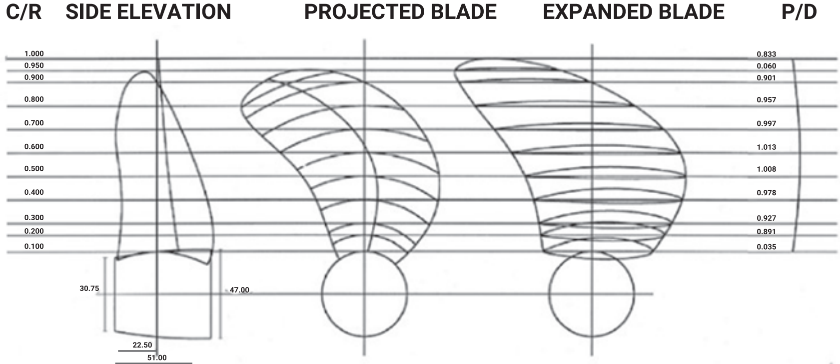

Figure 4: Sketch of KP505 Propeller Blade [9].

5. Computational Domain and Mesh Generation

An overview of the computational domain is shown in **Figure 5**. The propeller, which is totally immersed in an endless ocean, is represented by the boundary conditions of the simulations. The outside zone, which is fixed, and the inner zone, which is rotating, comprise the computing domain.

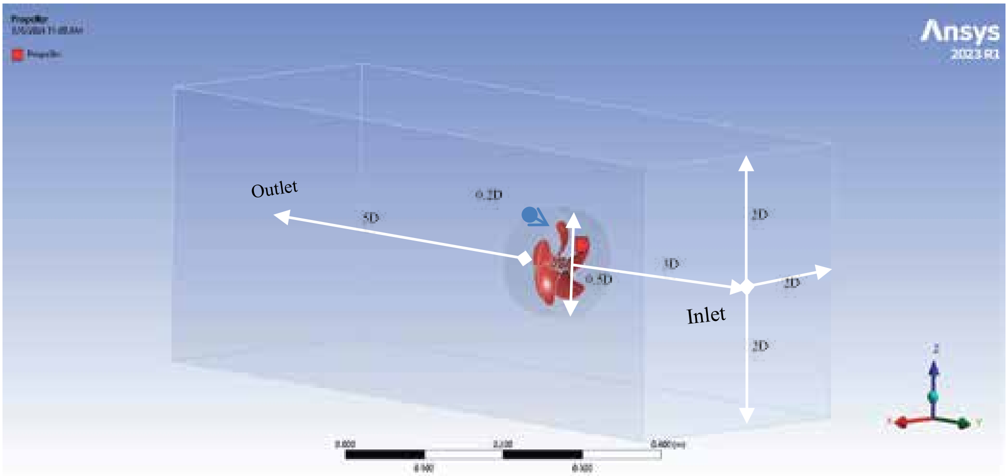

Figure 5: Computational Domain

The computational domain for propeller open water simulations is a rectangular shape with dimensions that are 4, 8, and 4 times the diameter of the propeller in the x, y, and z directions, respectively. The rectangular block was split into six boundary surfaces named inlet, outlet, top, bottom, left side and right side. **Table 2** shows the size and boundary condition of the computational domain. The downstream section of the propeller has a length of 5 diameters, while the upstream section has a length of 3 diameters **(Figure 5)**. The coordinate system is positioned at the precise midpoint of the propeller. The y-axis is directed towards the upstream, whereas the x and z axes are directed laterally and vertically, respectively. In relation to the boundary conditions, the velocity and direction of the inflow approaching the propeller are specified at the inlet boundary. This represents the water flow entering the computational domain, simulating open water conditions. At the outlet boundary, pressure outlet is applied to ensure that fluid leaving the computational domain does not introduce spurious reflections or disturbances back into the flow field as well as to maintain a consistent flow regime.

Table 2: Size and boundary condition of the computational domain

Boundary Name	Direction	Location	Boundary Condition
Inlet	y direction	3D	Velocity inlet
Outlet	y direction	-5D	Pressure outlet
Top	z direction	2D	Wall
Bottom	z direction	-2D	Wall
Left Side	x direction	2D	Wall
Right Side	x direction	-2D	Wall

In this analysis meshes are created using the built-in ANSYS Meshing Tool. The unstructured triangular prism grids are applied in meshing the domains shown in **Figure 6**. Element quality mesh metrices are maintained while the total number of elements and nodes are 2.4M and 0.4M, respectively.

ANSYS Fluent utilizes the implicit solver RANSE. The k-ω SST turbulence model with wall function formulation is employed for turbulence closure. The velocity-pressure coupling is managed using the pressure equation formulation known as SIMPLE, which employs a face-based approach.

6. Result and Discussion

To conduct the numerical simulation for the propeller's open water convergence test, a specific type of mesh consisting of 2.4 million cells is generated. The analysis investigates different values of advance coefficients (J) spanning from 0.2 to 0.8. Table 2 displays the results of this study, comparing experimental (EFD) and computational (CFD) data for the performance characteristics of the KP505 propeller under various operational conditions. The

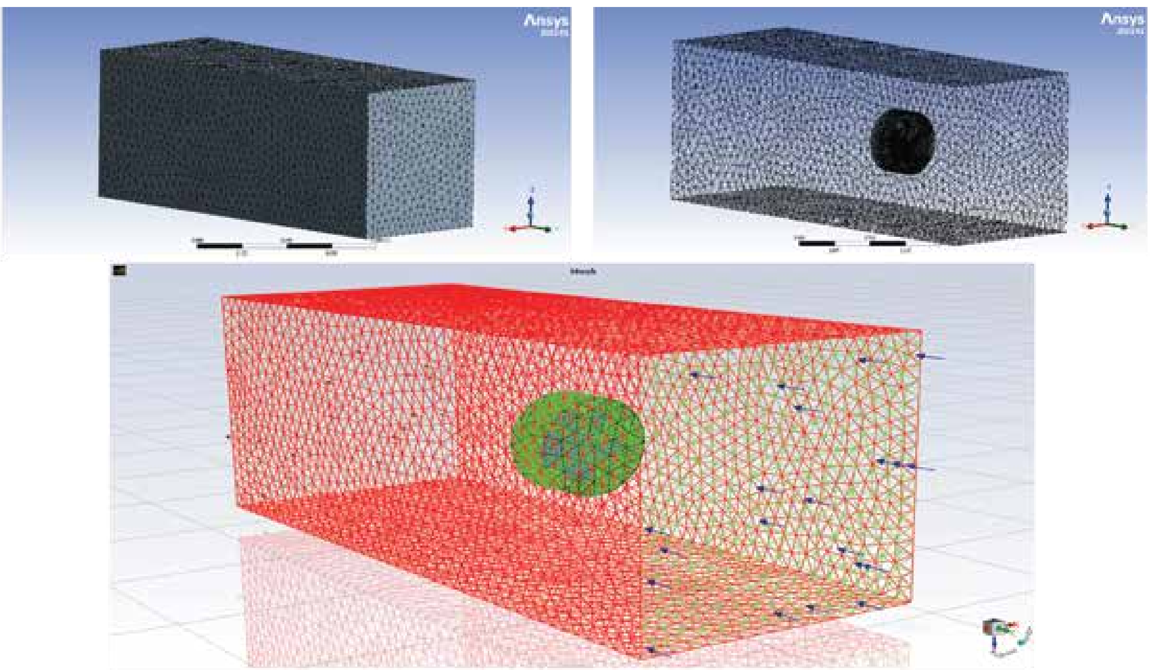

Figure 6: Grid System

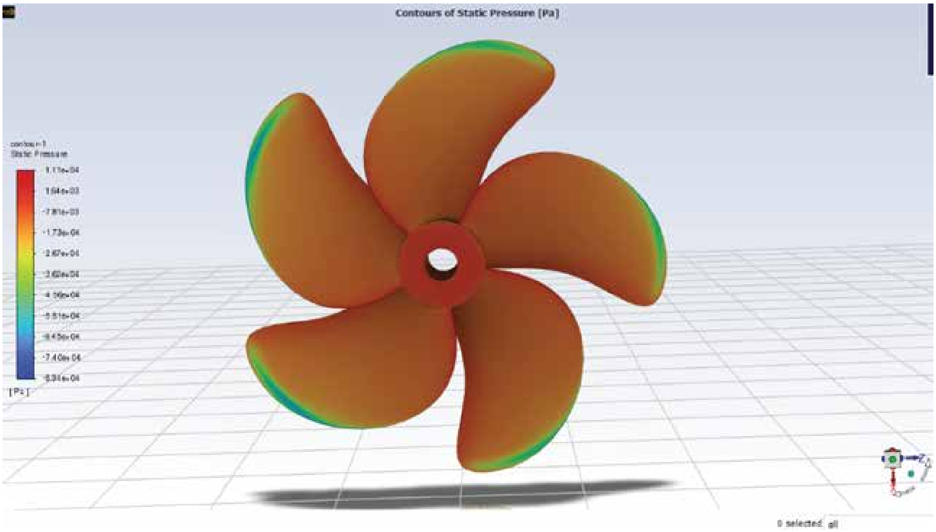

Figure 7: Static Pressure Distribution

analysis focuses on two key performance metrics: thrust coefficient (KT) and torque coefficient (KQ), observed across different advance coefficients (J) ranging from 0.2 to 0.8. For the thrust coefficient (KT), the experimental results (EFD) show values ranging from 0.4469 to 0.1414, while the computational results (CFD) range from 0.4274 to 0.1346. Overall, the CFD results exhibit slightly lower values compared to the EFD results across all advance coefficients. The percentage differences (ε %) between the EFD and CFD results range from -4.36% to -4.81%, indicating a slight underestimation of thrust coefficient by the CFD method compared to experimental measurements. Similarly, for the torque coefficient (KQ), the EFD results range from 0.6538 to 0.2805, while the CFD results range from 0.6900 to 0.2985. In this case, the CFD results tend to be slightly higher than the EFD results across all advance coefficients. The percentage differences (ε %) between the EFD and CFD results range from 1.66% to 6.61%, indicating a small overestimation of torque coefficient by the CFD method compared to experimental measurements. Overall, the comparison between experimental and computational results suggests reasonably good agreement between the two methods for predicting the performance characteristics of the KP505 propeller. However, some discrepancies are observed, with the CFD method tending to slightly underestimate thrust coefficient and slightly overestimate torque coefficient compared to experimental measurements. These differences could be attributed to numerous factors, including modeling assumptions, numerical approximations, and experimental uncertainties, which warrant further investigation and validation.

Table 3: EFD and CFD comparison of the open water propeller performance coefficients.

	K_T				$10*K_Q$			
J	**0.2**	**0.4**	**0.6**	**0.8**	**0.2**	**0.4**	**0.6**	**0.8**
EFD	0.4469	0.3425	0.2407	0.1414	0.6538	0.5314	0.4090	0.2805
CFD	0.4274	0.3562	0.2519	0.1346	0.6900	0.5665	0.4158	0.2985
ε %	-4.36	4.00	4.65	-4.81	5.54	6.61	1.66	6.42

The numerical simulation of propeller in open water also includes both the static and dynamic pressure distribution across the different region of the propeller. **Figure 7** shows the variations in pressure gradients which indicate areas of high and low pressure determining the forces acting on the propeller blades. Peaks in the pressure distribution correspond to regions of increased flow resistance or compression occurring near the leading edges of the propeller blades and in the areas of flow separation. The figure also illustrates pressure recovery downstream of the propeller, where the static pressure gradually returns to ambient levels as the flow re-establishes itself in the wake region.

The dynamic pressure distribution is one of the most important parameters in analyzing the propeller in open water condition for assessing the performance and efficiency of the propeller design. Regions of high dynamic pressure experience increased drag or load, potentially affecting propeller efficiency and inducing structural stresses. Conversely, regions of low dynamic pressure indicate areas where cavitation or flow separation could occur, impacting performance negatively. **Figure 8** illustrates how dynamic pressure varies along the span of the propeller blades. Higher dynamic pressures indicate regions where the fluid flow exerts greater force on the blade surfaces, while lower dynamic pressures correspond to regions with less force exerted by the fluid. The illustration depicts a notable trend in dynamic pressure across the propeller blades, where the pressure increases gradually from the central region towards the edges. At the

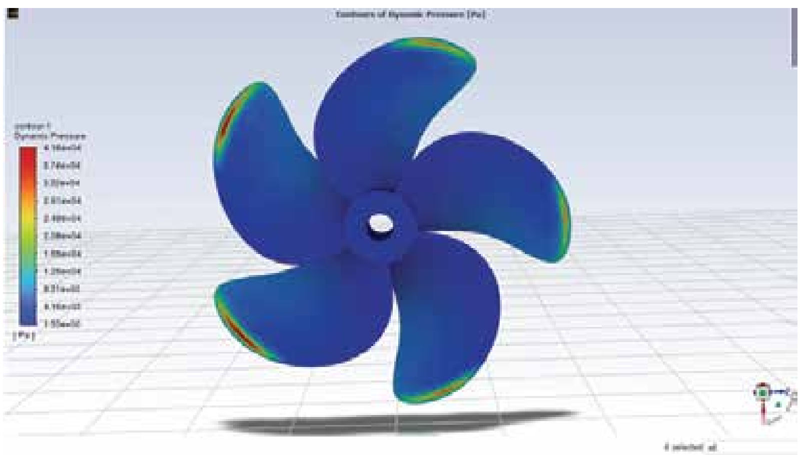

Figure 8: Dynamic Pressure Distribution

outermost edges of the blades, the dynamic pressure peaks, reaching its maximum value. This observation suggests that the outer edges of the propeller blades experience the highest force exerted by the flowing fluid, indicative of significant hydrodynamic loads in those areas.

7. Conclusion

This research paper has presented a comprehensive hydrodynamic analysis of the KP^{505} propeller operating in open water conditions using a computational method. Through detailed simulations and analysis, the contributions of key parameters including thrust and torque coefficients, as well as pressure and velocity distributions are investigated along the propeller blades. The variations in thrust and torque coefficients are observed under different operating conditions which influences the propeller's efficiency and performance characteristics. In some cases, there's a slight discrepancy between the EFD and CFD values for both KT and KQ. The percentage differences (ε %) are generally small, ranging from -4.81% to 6.61%, which is relatively good agreement between the EFD and CFD results. However, there are a few instances where the percentage difference exceeded 5% while determining torque coefficient under different operating conditions.

The minor variation between experimental and computational results indicates the differences of principle setup in these two methods. This research primarily focused on computational simulations. Real-world factors like hull interaction and wave effects are not explicitly incorporated in this study. Additionally, the accuracy of the CFD results depends on the chosen turbulence models and mesh generation techniques. Future studies could explore the combined effects of propeller-hull interaction and waves on the overall performance. Moreover, the scope of the study is limited to the KP505 propeller, and the findings may not be directly applicable to other propeller designs without appropriate validation and verification. Further investigation and refinement of the computational model can be warranted for those specific operating conditions where the deviation of computational results is slightly higher than the experimental results.

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OPPORTUNITIES AND CHALLENGES OF AUTONOMOUS VESSELS IN SHIPPING: A BRIEF SYSTEMATIC REVIEW

Md. Mahedi Hasan Bappy[a]*, Md Ashraful Islam Opi[b], Md Kutub Uddin[c], Farhana Arzu[d]

ABSTRACT

The emergence of autonomous vessels in the shipping industry presents promising opportunities and significant challenges. This systematic review aims to explore and summarize the current landscape of opportunities and challenges associated with autonomous vessels in shipping. By synthesizing existing literature, this review provides insights into the potential benefits of autonomous vessels, such as improved safety, efficiency, and environmental sustainability, alongside the various hurdles to their widespread adoption, including technological limitations, regulatory frameworks, and societal acceptance. Stakeholders in the maritime sector need to understand the complex connection between opportunities and challenges to pursue autonomous shipping effectively. By employing autonomous vessels and effectively addressing the related challenges, the marine industry will move towards safer, more efficient, and environmentally sustainable operations. This will bring about a new era of innovation and advancement on the high seas.

Keywords: Autonomous vessel; Shipping industry; Opportunities; Challenges; Systematic review.

1. INTRODUCTION

In the maritime context, shipping specifically pertains to transporting products via ships across the ocean. It encompasses the movement of goods between ports, including the arrival and departure from the ports. Over the past fifteen years, the shipping industry has encountered various obstacles, including the 2008 financial crisis, the sluggish economic recovery, excess shipping capacity, and the bankruptcy of a major company in 2017. Furthermore, the current shift towards energy sources less reliant on fossil fuels may impact the demand for shipping. The sector is seeking new ways to enhance demand and reduce operational expenses.

In recent years, the maritime industry has witnessed a paradigm shift with the integration of autonomous vessels, heralding a new era in shipping. Autonomous shipping is the capability of a ship to autonomously govern its actions during the transportation of commodities between ports [1]. Autonomous vessels, also known as unmanned surface vessels (USVs) or autonomous surface ships (ASVs), represent a groundbreaking advancement in maritime technology. They promise enhanced efficiency, safety, and sustainability in the transportation of goods across the world's oceans. As the global demand for maritime transportation continues to grow, fueled by expanding international trade and the need for efficient logistics solutions, the integration of autonomous vessels into shipping operations presents both unprecedented opportunities and formidable challenges.

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In 2017, the International Maritime Organization (IMO) initiated a regulatory scoping exercise to address the potential problems associated with Maritime Autonomous Surface Ships (MASS), as documented in the work [2]. Considering the increasing demands of international legislation, there is a growing interest in maritime alternative fuels that offer safer, more environmentally friendly, and more efficient ships [3]. Autonomous shipping is being considered and investigated for several reasons, as outlined by Porathe et al. [4]. These include the desire to improve working conditions for crews and address the potential shortage of seafarers. Additionally, there is a focus on reducing transportation costs, meeting global emissions reduction goals, and enhancing safety in the shipping industry.

Ships are increasingly employing sensors and artificial intelligence (AI) systems to navigate, steer, and avoid collisions, although this technology is still in its early development. Like cars, these developments should improve safety and efficiency while using cleaner fuels and engines to reduce environmental impact.

Autonomous vessels could leverage advanced algorithms to meticulously plan routes that minimize fuel consumption. This translates directly to lower emissions of greenhouse gases and other pollutants that plague the maritime sector. Furthermore, without the need to prioritize crew comfort or fatigue, unmanned ships could operate at slower speeds, which naturally translates to burning less fuel and producing fewer emissions. An even more significant environmental benefit emerges when considering the possibility of integrating cleaner energy sources. The absence of a crew opens the door to exploring alternative propulsion systems like hydrogen fuel cells or wind power. These cleaner options have the potential to drastically reduce emissions compared to the traditional reliance on fossil fuels.

This is extremely crucial: Maritime channels convey around 11 billion tons annually, accounting for around 80% of global trade. The shipping industry accounted for almost 3% (roughly 1,000 million tons) of worldwide carbon dioxide emissions in 2018. The International Marine Organization (IMO) has committed to achieving a 50% reduction in greenhouse gas emissions from the marine industry by the year 2050 [5].

Figure 1: Ultra-low emission, smart and autonomous vessels of the future [6].

Autonomous uncrewed or self-navigating vessels represent a transformative leap in the maritime industry. The market for autonomous ships was estimated to be valued at USD 3.9 billion in 2022. It is expected to grow to USD 8.2 billion by 2030, with a compound annual growth rate (CAGR) of 9.6% from 2022 to 2030 [7]. The concept of autonomous vessels encompasses a wide range of capabilities, from remotely controlled ships to fully autonomous vessels capable of navigating and making decisions without human intervention. These vessels leverage innovative technologies such as artificial intelligence (AI), machine learning, advanced sensors, and satellite communication systems to perceive their environment, plan routes, and execute complex maneuvers autonomously. By reducing human error and fatigue, autonomous vessels have the potential to improve safety at sea, mitigate the environmental impact of shipping, and optimize the utilization of resources.

Despite the growing body of literature examining the opportunities and challenges of autonomous vessels in shipping, there is a notable absence of comprehensive review papers synthesizing existing research on this topic. While individual studies provide valuable insights into various aspects of autonomous shipping, there is a need for a systematic review that consolidates and critically evaluates the findings across multiple disciplines. Such a review would help identify key themes, gaps, and inconsistencies in the literature, as well as provide a more nuanced understanding of the overall state of knowledge on autonomous vessels in shipping.

This systematic review seeks to thoroughly examine the opportunities and challenges related to autonomous vessels in the shipping industry, taking into account the aforementioned issues. By analyzing existing literature and empirical evidence on autonomous vessels, this study aims to provide policymakers, industry stakeholders, and researchers with valuable insights into the future of marine transportation.

1.1. Advancing towards autonomous shipping

The emergence of autonomous shipping is an ongoing narrative, with its origins dating back several decades. It was fueled by technological advancements and a desire to improve efficiency, safety, and environmental impact within the maritime industry.

1.1.1 Early Inception (1950s-1980s)

The mid-20th century witnessed the early exploration of automation concepts in shipping. Autopilots for course control emerged, laying the foundation for more sophisticated automation technologies. Limited remote-controlled ship operations were attempted, primarily for military applications. These early endeavors provided valuable insights into the potential of remote control and its associated challenges.

1.1.2. Technological Advancements (1990s-2000s)

The widespread adoption of Global Positioning Systems (GPS) and improved communication infrastructure provided a critical foundation for autonomous navigation and data exchange. Advancements in sensor technology, including radar, lidar, and cameras, enabled the development of more sophisticated perception systems for autonomous vessels. Research projects and concept designs for autonomous ships emerged, showcasing the potential for unmanned operations in controlled environments.

1.1.3. Shifting Focus and Growing Interest (2010s-Present)

As technology matured, feasibility studies explored the economic viability of autonomous ships for commercial applications. Potential cost savings and efficiency gains garnered significant industry interest.

Collaborative efforts between governments, maritime companies, and research institutions accelerated the development and testing of autonomous ship prototypes.
The concept of varying degrees of autonomy gained traction, from automated functions on manned vessels to fully autonomous operations. International Maritime Organization (IMO) discussions commenced addressing regulatory frameworks and safety standards for autonomous vessels.

1.1.4. Current Landscape

Real-world testing of autonomous vessels in controlled environments is underway, with various prototypes undergoing trials to gather data and refine technology.

The marine industry has recently demonstrated a growing inclination towards creating autonomous solutions to enhance operational efficiency, punctuality, and safety [8], [9]. For instance, the MUNIN (MUNIN is the abbreviation for Maritime Unmanned Navigation through Intelligence in Networks is a project that aims to create technology for a ship that can navigate without human intervention) research project examined safety and autonomy in a dry bulk carrier used for deep-sea shipping [10]. Additionally, DNV showcased its ReVolt concept to investigate crewless short-sea shipping [11]. In addition, Rolls Royce presented a self-driving boat in Finland, demonstrating its ability to combine sensor data, identify impediments, prevent collisions, and dock automatically [12]. The objective of the AUTOSHIP (The Autoship project has successfully revolutionized the maritime industry by testing and developing fully autonomous navigation systems, intelligent machinery systems, self-diagnostics, prognostics, and operation scheduling. It is all about pushing the boundaries of what is possible on the high seas) research project was to construct, evaluate, and operate two self-governing vessels equipped with the ability to navigate in both short-sea shipping and inland waterway situations [13]. The Suzaku, a commercial vessel in Japan, recently underwent a 790-kilometre trial to assess its ability to navigate autonomously. This trial specifically focused on the ship's navigation capabilities utilizing a container ship [14].

In January 2022, the Soleil, a car ferry from Japan, achieved the distinction of being the inaugural large-scale vessel to operate autonomously without any human interference. The 220-meter-long vessel autonomously docked and undocked, changed direction, reversed, and navigated itself for 240 km across the Iyonada Sea, starting from Shinmoji in northern Kyushu. These operations are often considered difficult even for experienced human operators [15].

Currently, small, fully autonomous boats less than 10 meters long are being used for specific purposes, such as monitoring water quality and infrastructure in the open sea. These boats also serve as test platforms for modern technology. However, there will be a significant transformation in the coming years, as the first major 'maritime autonomous surface ships' are scheduled to commence commercial operation.

The pilot projects encompass the Yara Birkeland, an 80-metre-long container ship from Norway. It is projected to transport fertilizer independently and without any emissions from a production facility to a shipping port by 2024 [16]. A 120-meter-long electric container ship, Zhi Fei, has been showcased in China. It operates under remote and occasionally autonomous supervision as it travels between two ports in Shandong province [17].

Figure 2: The Norwegian container ship Yara Birkeland.

Within a decade, autonomous vessels could potentially engage in mutual interactions. An example is the Vessel Train, a pilot initiative supported by the European Union and managed by the Netherlands Maritime Technology Foundation in Rotterdam. The Vessel Train employs a manned lead vessel to lead a group of smaller automated vessels, allowing them to navigate tiny waterways near ports efficiently. Ultimately, groups of autonomous vessels might be supervised from onshore maritime traffic-control centers.

The autonomous shipping revolution is a complex journey with immense potential and significant hurdles. As technology continues to evolve and collaborative efforts progress, autonomous vessels have the potential to reshape the maritime landscape, leading to a future of efficient, safe, and sustainable shipping. While the exact timeline for widespread adoption remains uncertain, the voyage towards an autonomous shipping future has begun.

1.1.5. Classifications of Autonomy Levels

The International Maritime Organization (IMO), Lloyd's Register, and Rolls-Royce have each established frameworks to define and categorize the levels of autonomy in maritime operations. These frameworks provide a structured approach to understanding the progression of autonomy, from manual control to full autonomy, with varying degrees of human involvement and computer decision-making capabilities.

Table 1: Autonomy levels defined by different international organizations.

Levels of Autonomy by IMO [18]	Levels of Autonomy by Lloyd's Register [19]	Levels of Autonomy by Rolls-Royce [20]
MASS 1.0 – Ship with automated processes and decision support. MASS 2.0 – Remotely controlled ship with seafarers on board. MASS 3.0 – Remotely controlled ship without seafarers on board. MASS 4.0 – Fully autonomous ship.	AL 0 – Manual steering. AL 1 – On-board decision support. AL 2 – On and off-board decision support. AL 3 – "Active" human in the loop. AL 4 – Human in the loop. AL 5 – Autonomous. AL 6 – Fully autonomous.	L 1 – The computer does not assist humans in charge of all decisions and actions. L 2 – The computer provides a complete set of decision alternatives. L 3 – The computer narrows alternatives down to a few. L 4 – The computer suggests a single alternative. L 5 – The computer executes the suggested action if the human approves. L 6 – The computer provides human beings with limited time to veto before automatic execution. L 7 – The computer operates automatically, when necessary, informing humans. L 8 – The computer informs humans only if asked. L 9 – The computer informs humans only if it decides so. L 10 – The computer does everything autonomously, ignoring humans.

The IMO's framework, known as the Maritime Autonomous Surface Ships (MASS) framework, outlines four levels of autonomy: MASS 1.0, MASS 2.0, MASS 3.0, and MASS 4.0. These levels represent different degrees of automation, ranging from ships with automated processes and decision support to fully autonomous ships.

Lloyd's Register defines autonomy levels (AL) across six stages, from AL 0 to AL 5, with an additional level, AL 6, for fully autonomous operations. These levels encompass manual steering, onboard decision support, onboard and offboard decision support, "active" human involvement, human-in-the-loop, and autonomous operations.

Rolls-Royce provides a more detailed breakdown of autonomy levels (L) from L 1 to L 10. These levels delineate the extent of computer assistance and human involvement, with L 1 representing no computer assistance and complete human control and L 10 indicating full autonomy where the computer autonomously performs all tasks without human input.

2. Methods

This review employs a systematic approach to gather and analyze relevant literature on autonomous vessels in shipping. A thorough search of academic databases (secondary data), industry reports, and grey literature was conducted using predetermined search terms related to autonomous shipping. The selected studies were screened based on inclusion and exclusion criteria to ensure relevance and reliability. The synthesized findings were categorized into opportunities and challenges, providing a structured analysis of the current landscape.

2.1. Literature Search

In this study, we used a systematic literature review to identify relevant research articles on Autonomous vessels in Shipping.
SCOPUS, launched in 2004 by the academic publisher Elsevier, is a database that contains abstracts and citations. It was used as the primary database for keyword searches as this is one of the largest globally used databases.

All papers available on SCOPUS were reviewed. Searched terms included "Autonomous vessels in Shipping," "Autonomous Shipping," "Challenges," or "Opportunities." The time frame, application areas, country, or journal did not limit the search.

2.2. Inclusion and Exclusion Criteria

The current study specifically examines Autonomous Vessels in Shipping and, as a result, excludes articles that discuss conventional shipping technology and other technological advancements in regular shipping that are irrelevant to the study's purpose. The current systematic literature review (SLR) only included original research publications undergoing peer review. Review articles, book chapters, notes, short surveys, letters, thesis, and editorials were excluded from consideration. In addition, the selected articles were only written in English, without any restrictions on the country of publication.

2.3. Data Extraction

A total of 2,330 articles were obtained from the Scopus Database during the initial database search. While there were no specific limitations on the timeframe, scholars have primarily focused on the works published from 2020 forward. Hence, particular articles were written within the last 5 years. Subsequently, the inclusion and exclusion criteria were applied, resulting in 52 publications that were selected for further examination of their titles, abstracts, and keywords. Reviewing the titles and abstracts, we excluded 17 articles irrelevant to our research. Following the comprehensive evaluations of the entire texts, 35 publications were determined to fall within the parameters of our study. Most research has been disregarded since it prioritized autonomy in other technical and engineering aspects of shipping. Thus, 35 papers were chosen for the systematic literature review (SLR) (Figure 3).

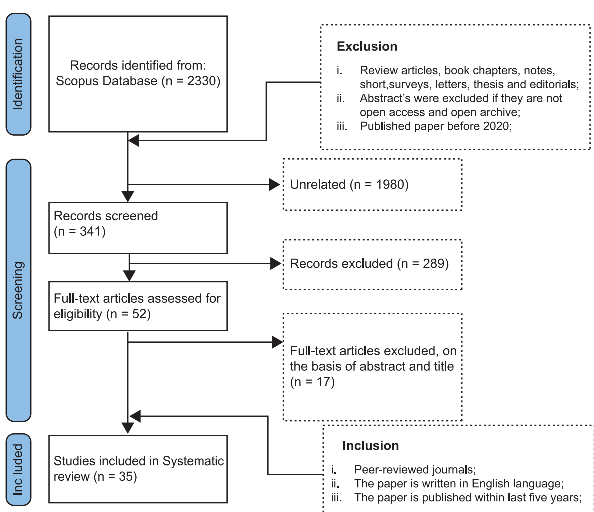

Figure 3: Search strategy. The figure shows the search strategy, including the database assessed for this study.

3. Contribution of Autonomous Vessels in Shipping Industry

3.1. Advance usage of technology

The fourth industrial revolution (Industry 4.0) refers to the ongoing transformation of traditional manufacturing and industrial practices through a fusion of advanced technologies.

Accomplishing shipping 4.0 the industry is rapidly evolving towards autonomous shipping. These ships are equipped with a myriad of sensors including radar, lidar, cameras, GPS, sonar, and Automatic Identification System (AIS), Route Optimization with AI, providing comprehensive situational awareness crucial for navigation and collision avoidance [21].

Conventional shipping relies heavily on human expertise and experience to navigate and operate vessels. Autonomous ships, on the other hand, leverage a suite of modern technologies to achieve independent operation. Autonomous vessels can be operated directly or using artificial intelligence, machine learning (ML), advanced sensors, and computer systems. The advantages of autonomous ships are enormous. They are safer, more efficient, and less harmful to the environment because they help decrease the chance of accidents, human error, and fuel consumption. The prospect of autonomous ships transforming the maritime business is both exciting and terrifying.

3.2. Reduction in operational cost

Marine automation and autonomy offer substantial cost-saving benefits for ship owners and operators. Predictive maintenance systems in Maritime Autonomous Surface Ships (MASS) lead to reduced crewing costs, lower insurance premiums due to improved safety records, and decreased maintenance expenses [22], [23]. Autonomous ships can operate at slower speeds without considering crew comfort, thus lowering fuel consumption and costs [24].

While advanced onboard technologies may increase initial capital expenditures (CAPEX) for comparable-sized ships, smaller vessels enhance flexibility and customer satisfaction in autonomous shipping. Larger fleets benefit from increased resilience, as the failure of one ship has less impact on the entire fleet, resulting in fewer disruptions to cargo operations [24], [25].

The maritime sector is increasingly drawn to autonomous operations, primarily to reduce crew size and enhance operational efficiency. By employing advanced ship designs and automation technologies, vessels can potentially operate with fewer crew members or even entirely unmanned.

In autonomous shipping, crew reduction opportunities are significant, with potential cost savings and operational efficiencies. The emergence of autonomous ships will inevitably result in a decrease in crew levels or potentially even fully unmanned ships. There are numerous advantages associated with sailing with a diminished crew size. Studies suggest that crew costs can be a substantial portion of operational expenses, making crew reduction a promising avenue for cost reduction [26]. Different concepts, such as replacing open water navigation or mooring tasks with automation, can substantially reduce crew costs and operational efficiencies [27]. Additionally, the transition to autonomous shipping involves scenarios where autonomous systems gradually replace crew members, improving maritime operations' safety, efficiency, and cost-effectiveness [28]. These crew reduction opportunities offer economic benefits and enhance safety and operational performance in autonomous shipping [29].

Crew-related operational costs for basic vessels include salaries and consumables (50%), management (32%), and maintenance and repairs (18%). With autonomous operations, staff costs can be reduced by 60–80% [27]. Overall, autonomous vessels can cost 12%-34% less than conventional ships, offering significant savings under various scenarios.

3.3. Safety Enhancement

Autonomous ships are anticipated to enhance maritime safety by reducing the risk of accidents caused by human error, which is a significant factor in most maritime incidents. Studies suggest that up to 90% of accidents at sea are attributed to human errors [30]. By removing the human element from navigation, autonomous vessels can potentially mitigate these risks and improve safety outcomes. Efforts to automate tasks like berthing and mooring procedures, both at ports and onboard ships, are expected to further enhance safety and streamline operations. Additionally, automation can simplify administrative processes at seaports, reducing expenses and delays associated with cargo imports and exports. Overall, the adoption of autonomous technology in the maritime industry holds promise for safer and more efficient operations.

3.4. Environmental Sustainability

Autonomous shipping brings significant environmental benefits, including reduced emissions and improved energy efficiency [31]. By employing energy-efficient technologies and optimizing operational processes, Maritime Autonomous Surface Ships (MASS) can decrease carbon emissions and enhance vessel performance [32]. Additionally, innovations like hydrogen or green ammonia propulsion contribute to lowering emissions, aligning with global climate goals and sustainable development objectives in the maritime sector. Autonomous underwater dredging can save 66% energy by reducing ship resistance and vacuum [33].

Advanced autonomous technologies, such as intelligent route planning and hybrid power plants, further improve fuel savings, emissions reduction, and system reliability. Hybrid designs, with multiple power sources, not only enhance reliability but also significantly reduce pollution and fuel consumption.

By having many power sources and customers, hybrid power plants increase system reliability and reduce pollution and fuel consumption. The hybrid construction saves 17% more gasoline than the standard diesel engine-powered setup [34]. Moreover, autonomous ships' intelligent operations lead to notable reductions in CO2 and NOx emissions compared to traditional vessels, making them key players in promoting marine industry sustainability. Using less auxiliary power reduces Transition Autonomous Ship (TAS) CO2 and NOx emissions by 3.6% to 3.9% and 3.9% to 4.2%, respectively. The Next Generation Autonomous Ship (NGAS) reduces CO2 and NOx emissions by 8.3–11% and 8.2–10% [27].

4. Challenges of Autonomous Vessels in Shipping

4.1. Technological Limitations

Autonomous technology still has technical issues despite tremendous progress. Sensor reliability, communication infrastructure, and cybersecurity risks hinder autonomous vessel adoption. MASS's technical limits focus on autonomous system safety and reliability, especially compared to crewed ship systems. Strong remote monitoring and management technologies from shore control centers (SCCs) are needed to prove autonomous systems can defend as well as manned vessels [35]. Satellite communication and sensor systems aboard warships are essential for SCC situation awareness, especially in emergencies. However, sensor failures threaten system safety, emphasizing the need for redundancy, diagnostics, and prognosis in sensor design. Integrating sensors and testing and inspecting them makes MASS technology development more difficult. Expert involvement is needed to address possible challenges to autonomous ship safety and efficiency, including computational flaws and a lack of failure data.

4.2. Cyber Security Risk

Autonomous ships are vulnerable to cybersecurity threats, including hacking, malware, and system vulnerabilities. Protecting onboard systems from cyber-attacks and ensuring data privacy are essential challenges that need to be addressed to safeguard autonomous vessels and maritime infrastructure.

There have been severe consequences from accidents led on by a failure to prevent cyberattacks, including loss of life, damage to property and reputation, financial losses, negative environmental effects, and more. For instance, a cyberattack in 2017 is said to have cost Maersk between $200 and $300 million. Cyberattacks at the COSCO terminal at the Port of Long Beach in 2018, the IMO, and CMA CGM in 2020 have caused multiple network failures [36].

The major challenge faced today by the security domain is developing the ability to identify patterns emerging within massive amounts of data fused from various sources and generated from monitoring thousands of vessels a day to act proactively to minimize the impact of threats.

4.3. Increase in Capital Cost

The initial expenditure for autonomous crewless vessels is larger than conventional vessels. In the best-case and worst-case scenarios, the capital expenditure of Transition Autonomous Ship increases by 8% to 17%, respectively. These increases are mostly related to autonomous systems, the utilization of necessary equipment, and the engine. Because of the absence of the deckhouse and crew-related structures and the reduction in steel and manufacturing costs, the capital expenditure of the Next Generation Autonomous Ship was predicted to be 3-5% less than the Transition Autonomous Ship [27].

4.4. Human AI Interaction

Human-AI interaction challenges in autonomous shipping include uncertainties in real-world conditions, risks related to integrating human supervisory control, and the need for transparent AI decision-making [37]. The lack of empirical data on failure propagation between hardware, software, and humans poses a significant obstacle, emphasizing the need for research in risk management frameworks suitable for MASS systems [38]. Studies emphasize the importance of human involvement in autonomous ship systems, especially in tasks like interpreting regulations and making decisions in complex situations.

4.5. Regulatory Frameworks

The autonomous shipping regulatory landscape is continually changing, causing industry stakeholders uncertainty and complexity.

K. Wróbel et al. [39] found that most autonomous shipping research focused on technological elements, indicating an underexplored topic. Technical components are well-explored due to prototypes, but organizational, legal, and regulatory concerns are undetermined but necessary for a safe and efficient autonomous shipping system [23], [39]. International norms for safety, security, and environmental soundness make MASS regulation difficult. Existing restrictions for human vessels may not adequately address autonomous ship characteristics, requiring new international norms [40]. Given the many agreements and requirement for harmonization, reaching regulatory standards consensus among states is difficult. Dynamic autonomous shipping, with vessels operating at different autonomy levels (Figure 4), complicates regulatory control [41]. Risk assessment, software quality assurance, and goal-based standards are crucial for MASS safety in

physical and virtual settings. IMO committees and subcommittees must collaborate to create comprehensive regulatory frameworks for autonomous shipping.

Liability, safety, and operational norms must be devised and harmonized to integrate autonomous vessels into maritime legislation.

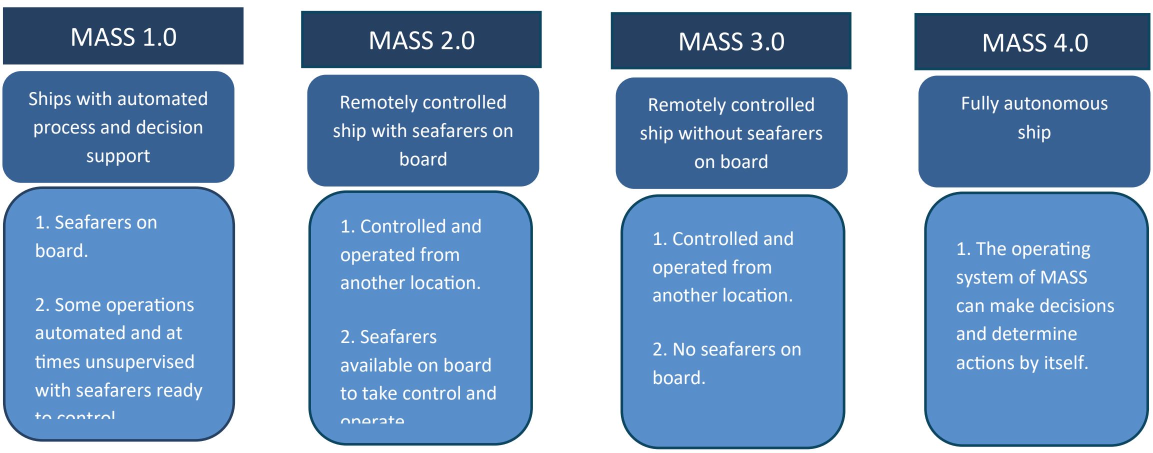

Figure 4: MASS's level of automation, according to IMO [41].

4.6. Social and Workforce Impacts

Public perception and acceptance of autonomous vessels are crucial in their adoption and deployment. Concerns regarding job displacement, safety, and ethical considerations must be addressed through transparent communication and stakeholder engagement initiatives. The transition to MASS has profound social and workforce implications, including concerns about job displacement, retraining needs, and the future of maritime labor. Automation and autonomy in maritime operations have the potential to reduce the demand for traditional seafaring roles, leading to unemployment and shifts in workforce dynamics [25], [42]. Ensuring a smooth transition to autonomous shipping requires investment in workforce development, education, and skills training to equip maritime personnel with the competencies needed for emerging roles in autonomous vessel operation, maintenance, and support [43].

Research conducted by T. Fonseca [25] indicates that ship owners and operators exhibit limited enthusiasm for autonomous shipping itself. However, they express significant interest in the foundational components of autonomy, aiming to enhance vessel intelligence and connectivity. This includes advancements onboard and onshore, such as establishing fleet control centers.

5. Recommendations

In navigating the complexities of autonomous shipping, it is evident that addressing technological, regulatory, and social challenges is imperative for the industry's advancement. To propel the adoption of autonomous vessels and ensure their safe and efficient operation, stakeholders must prioritize strategic initiatives across various fronts. This SLR presents several suggestions aimed at mitigating the challenges faced within the realm of autonomous shipping.

5.1. Enhancing Technological Reliability

To address technological limitations in MASS, it is imperative to invest in robust sensor reliability, communication infrastructure, and cybersecurity measures. Research and development should prioritize redundancy, diagnostics, and prognosis in sensor design to mitigate the risks associated with sensor failures. Furthermore, integrating expert involvement in MASS technology development can help tackle challenges related to computational flaws and insufficient failure data.

5.2. Strengthening Cybersecurity Measures

Mitigating cybersecurity threats in autonomous shipping requires a multi-faceted approach. Investing in advanced cybersecurity measures, such as intrusion detection systems and encryption protocols, is crucial. Additionally, continuous monitoring and updating of onboard systems for vulnerabilities are essential. Collaboration between industry stakeholders, regulatory bodies, and cybersecurity experts can help establish comprehensive cybersecurity frameworks to safeguard autonomous vessels and maritime infrastructure.

5.3. Optimizing Capital Expenditure

While the initial capital expenditure for autonomous vessels may be higher than conventional vessels, there are opportunities to optimize costs. Research and development efforts should focus on streamlining autonomous systems, optimizing equipment utilization, and exploring cost-effective engineering solutions. Additionally, leveraging economies of scale and advancements in manufacturing technologies can help reduce capital costs for autonomous vessels in the long term.

5.4. Improving Human AI Interaction

Addressing challenges in human-AI interaction requires a nuanced approach. Research efforts should prioritize understanding real-world conditions and integrating human supervisory control transparently into autonomous ship systems. Developing risk management frameworks tailored for MASS systems and fostering collaboration between academia, industry, and regulatory bodies can facilitate the responsible integration of AI in maritime operations.

5.5. Establishing Comprehensive Regulatory Frameworks

Establishing comprehensive regulatory frameworks for autonomous shipping necessitates collaboration and consensus-building among international stakeholders. Regulatory bodies such as the IMO should prioritize addressing organizational, legal, and regulatory concerns alongside technical aspects. Emphasizing risk assessment, software quality assurance, and goal-based standards can ensure the safety and efficiency of autonomous shipping systems while navigating the complexities of international norms and agreements.

5.6. Addressing Social and Workforce Impacts

To address social and workforce impacts of autonomous shipping, proactive measures are essential. Transparent communication and stakeholder engagement initiatives can help alleviate concerns regarding job displacement, safety, and ethical considerations. Investing in workforce development, education, and skills training can prepare maritime personnel for emerging roles in autonomous vessel operation, maintenance, and support. Additionally, fostering collaboration between shipowners, operators, and technology providers can drive innovation and enhance vessel intelligence and connectivity while addressing industry concerns.

6. Conclusion

In conclusion, the integration of autonomous vessels in the shipping industry offers numerous opportunities and challenges, as highlighted by this systematic review. These vessels promise enhanced shipping efficiency and cost-effectiveness by operating round-the-clock without crew rest requirements and employing autonomous navigation systems for route optimization. Future advancements in maritime transport, including smart ships, electric propulsion, and hybrid technologies, aim to reduce emissions, congestion, and waiting times while increasing productivity and sustainability. However, the widespread adoption of autonomous vessels presents significant safety, regulatory, and infrastructural hurdles that need to be addressed collaboratively by stakeholders in the maritime sector. Despite these challenges, the future of autonomous ship technology appears promising, with expectations for their deployment on short-distance ferries and inland waterway vessels by 2030. To fully harness the benefits of autonomous vessels, concerted efforts are required to overcome regulatory uncertainties, ensure safety standards, and invest in infrastructure and training. By addressing these issues, the maritime industry can usher in a safer, more efficient, and sustainable era of sea transportation.

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MAN-HOUR ESTIMATION AS AN AID TO COST AND OPERATIONAL ANALYSIS OF SHIP MAINTENANCE YARDS IN BANGLADESH

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ABSTRACT

Man-hour estimation helps gauge repair and maintenance costs at Bangladesh's maintenance yards. These yards are key to the country's GDP growth, providing jobs and ensuring inland and coastal vessels meet IMO and local regulations. This supports the growth of Bangladesh's shipping industry. Both private and government maintenance yards play a key role in repairing various types of vessels. Despite challenges, a strong workforce including marine engineers, naval architects, and other skilled workers support this industry. Man-hour estimation is crucial for planning and managing repair and maintenance efficiently. This study explores the application of man-hour estimation in optimizing maintenance and repair operations at Bangladesh Inland Water Transport Corporation (BIWTC) dockyards. As a crucial player in Bangladesh's maritime sector, BIWTC dockyards play a pivotal role in sustaining the country's economy through efficient ship maintenance and repair services. This research primarily focuses on the estimation of man-hours as a metric for assessing and enhancing labor utilization and cost-effectiveness in ship repair operations. The findings indicate significant variance in man-hour utilization based on vessel type and maintenance activity, underscoring the potential for optimized scheduling and resource allocation. The study concludes with key recommendations for BIWTC, including the adoption of advanced scheduling tools, enhanced training, and strategic private partnerships to improve efficiency and reduce costs. This research offers valuable insights for enhancing the economic impact of maritime logistics and ship repair in developing economies.

Keywords: Man-hour; ISO; MSO; MSMD; BIWTC; BIWTA; Ship Maintenance.

1. INTRODUCTION

In Bangladesh, shipbuilding or ship repair are mostly labor-oriented and labor cost is significant factor for this industry. The amount of labor expenditure shares the second highest cost comparing with the materials and machineries cost. Optimum and effective man-hour estimation can reduce the total cost to some extent. The shipbuilding or ship repair yards have to deal with a variety of products. In order to ensure minimal profit margins pricing is very important. The estimation of man-hour is a significant part of shipbuilding or ship repair cost. Cost of labor in ship building is typically around 20-30% of the total ship manufacturing cost [1]. Ship maintenance usually are carried out in shipyard and dockyard. Typically 75% of the work involves routine ship maintenance, and the remaining 25% is for damage repair and ship conversion [2]. Ship's operating costs vary according to type, size and age of vessel. According to the Inland Shipping Ordinance (ISO) 1976, Clause No-30(1) states that, "subject to the other provisions of this ordinance, a certificate of registry of an inland ship granted under this ordinance shall remain valid for 30 (thirty) years of her age from the date of first registry unless the ship is rendered total loss, scraped or otherwise transformed within the said period. Provided that the validity of the registration may be extended, if it is found that the inland ship is fit for plying to the satisfaction

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of the register after special docking survey in a manner as may be prescribed, for a maximum period of five years and continued for the same further period subject to special docking (ISO-76). Therefore ship repair for special docking has a significant role to increase the life span of any vessel. Thus operating cost like man-hour estimation of a ship has taken on significance in the pursuit of shipping business survival. The labors employed in ship building process can be divided into (a) Direct or indirect shipbuilding labors (b) Direct or indirect shipbuilding contractors [3]. The complex and complicated ship repair process can be simplified by work breakdown structure (WBS). Wan Abd Rahman stated that, the common WBS used for shipyards or dockyards is Program Work Breakdown (PWBS), Contract Work Breakdown Structure (CWBS), Ship Work Breakdown Structure (SWBS), SFI Group system, Product Work Breakdown Structure (PWBS) and Zone Work Breakdown Structure (ZWBS) [4]. The SFI group system WBS was developed at the Norwegian Ship Research Institute (Senter for Forskningsdrevet Innovasjon-SFI), now known as MARINTEK to provide the international standard reference in cost management. Today, Singapore has the biggest repair capacity in the world. The strength of the industry lies in its breadth and depth with comprehensive ancillary activities, making Singapore a comprehensive "one stop" marine complex [5]. Ship repairing time is composed of two parts, the first part is the time inside the dock (docking time) and the second part is the time at the jetty side (berthing time). During docking time, the main concentration is on the bottom surveys and underwater jobs, which cannot be done in afloat conditions. During berthing time, all other jobs, except underwater jobs, are conducted [6] [7]. The ship repair industry is growing day by day in Bangladesh. Man-hour estimation is very significant to survive in the competitive ship repair industry. As scheduled ship repair demand represents the pre-planned ship R&M work, the unscheduled demand represents the repair work that has to be carried out when something unexpected has forced the ship to stop operation [8]. Water transport is very popular in Bangladesh because of the low cost and comfortable travel by river. At present, about 50% of the inland river vessels carry commercial cargo and one-fourth are involved in passenger transport. This is making a significant contribution to our GDP growth. Every year, various types of vessels are increasing as well as the volume of repair and maintenance works are also rising. So maintenance yards are playing an important role to enhance the capacity of maritime sector of the country which is also contributing directly and indirectly to the GDP growth as well as blue economy. Bangladesh is situated in the funnel shaped coast of the Bay of Bengal. Due to her geographical location, a large number of rivers flow through the country towards the Bay of Bengal forming a strong river network. The cheapest water transportation is considered as very powerful and essential means of communication in this country. In places inaccessible by land, water transport acts as the only gateway of communication with rest of the country. Mostly of ferries, passenger vessels, oil tankers, cargo vessels, tankers, tugboats, salvage vessels, fishing vessels and dumb crafts ply in the inland water ways of Bangladesh. The static carrying capacity of the IWT fleet is about 0.20 million passengers and 0.55 million tons cargo. In terms of carrying capacity, the private sector outweighs the contribution of the public sector both for the passenger and cargo movement (private sector 93% for passenger and 95% for cargo). The coastal water ways is playing significant role for the growth of the country. Especially the passenger vessels have made the communication system easier for the coastal areas like Bhola, Monpora, Sandeep and Saint Martin Island. Fishing vessels are contributing in the blue economy and Bangladesh owns a large area at Bay of Bengal as the fishing hub. Inland ferries are making the communication system easier by connecting the roads to carry passengers as well as goods by buses and trucks. Inland oil tankers are ensuring the oil supply network across the whole country. As a white listed member of IMO, Bangladesh has to comply with inland and coastal rules and regulations to ensure the safe navigation as well as to establish a smart maritime country. Minimum Safe Manning Document (MSMD) of Merchant Shipping Ordinance (MSO), 1983 states that as per the regulation the costal vessels need personnel with having class-IV & V COC, whereas the inland vessels can navigate with the personnel having inland class-I COC and other crews. Shipyards or Dockyards have different technical personnel like Marine Engineer, Naval Architect, Mechanical Engineer, Offshore Engineers, Electrical Engineer, Platter, Welder, Mechanic, Pipe Fitter, Turner, Draftsman, Electrician, Carpenter, Painter and other trades as per the requirement. According to a Danish study, existing labor cost in Bangladesh on an average is around US $ 1.5 dollar per hour, which is US $ 3 in China, US $ 8 in South Korea, US $ 16 in Italy and US $ 18 in the United States [9]. So, human resource is an asset and man-hour estimation in ship repair can ensure the optimum utilization of that asset. This paper explores ship repair in Bangladesh, focusing on how labor costs impact the industry's efficiency. The study seeks to comprehend the costs of repairing various vessel types at different shipyards in Bangladesh and explore how estimating work hours can mitigate overall expenses. Through comparing ship repair costs in Bangladesh with those elsewhere, the aim is to pinpoint cost-effective dockyards. Ultimately, the objective is to offer practical recommendations for enhancing the efficiency and sustainability of ship repair in Bangladesh.

2. Methodology

Secondary data have been used in this study. The resources of secondary data used in the study are: Report of Ship Repair Statistics, Bangladesh Shipyard Statistics, BIWTC, BIWTA, World Maritime News and other relevant text, Journals and web documents etc. To get real data and developing a proper and meaningful understanding, visited different dockyards and various ships to explore the potentialities and problems of this industry.

2.1. Data Collection

Bangladesh Inland Water Transport Corporation (BIWTC) was formed under the Presidential Order No. 28 in 1972 with the assets of erstwhile East Pakistan Shipping Corporation, Pakistan River Steamer Services and 8 others unit of abandoned shipping companies. Bangabandhu Sheikh Mujibur Rahman shows his supreme vision of maritime Bangladesh and the legacy of creativity to build Sonar Bangla through the economic development of post-independence war-ravaged Bangladesh. Mohammadullah outlined BIWTC's objectives: recommission damaged watercraft and repair yards, restore riverine and coastal transportation, reestablish links with offshore islands, ensure safe and efficient freight and passenger transport, and maintain minimal freight levels, preventing speculation in private operati`ons.

It is the only public sector corporation in the inland and coastal water ways of Bangladesh, which was started functioning with 611 vessel of various types [10]. Currently BIWTC has 04 (four) dockyards and 01 (one) floating dockyard at Narayangonj. The 04 (four) dockyards are named as Dockyard no-1, which has lifting capacity of 500 Metric Ton, Dockyard no-2, which has lifting capacity of 1000 Metric Ton, Dockyard no-3, which has lifting capacity of 150 Metric Ton and Dockyard no-4 which has lifting capacity of 350 Metric Ton. The Floating Dockyard has the lifting capacity of 750 Metric Ton. Dockyard no-1 has the repair facilities for K-type ferries, Medium ferries, Utility ferries, Pontoons, Floating Workshops Tugboats. Floating Dockyard has the repair facility for Improved Medium ferries, Ro Ro Ferries, K-type ferries and Tug boats. Dockyard no-2 has the repair facility for Ro Ro ferries, Passenger vessels, K-type ferries and Tug boats. Dockyard no-3 has the repair facility of Sea-truck and water bus. Dockyard no-4 has the repair facility of Pontoons, K-type ferries and Tugboats. In order to extend the ship repair facilities BIWTC is constructing two new slipways with lifting capacity of 2000 Metric Ton and the development planning has taken regarding the capacity enhancement of dockyard no-3 and dockyard no-4. BIWTA also has a Floating Dockyard at Narayangonj which has the ship repair facility for Pontoon, Salvage vessels, Ferries and other vessels. Highspeed Shipyard and Meghna Shipyard also have the ship repair facility of type of vessels.

Based on this sample calculation of Table 1 the data has taken for different type of vessels with variety of ship particulars and dimensions. It is to be mentioned here that despite of having many repair works few major repair works have been assumed to estimate the man hour for every type of vessels and plotted the graphs accordingly.

3. Data Analysis

3.1. Man hour for Dock Services

Man hour has been estimated for dock services of 5, 7, 10, 12, 15 days for different type of vessels. Also calculated the average and standard deviation of man hour for dock services. Based on the found data the graph is plotted, where the inland passenger vessel required maximum man hour for dock services like fire and safety watchman per day, garbage skip per day, electrical shore power connection and disconnection, electrical shore power per unit, temporary connection of fire main to ship’s system, maintaining pressure to ship’s fire main per day, sea circulating water connection, sea circulating water per day, telephone connection onboard ship, supply of ballast water per connection, supply of fresh water per connection, connection and disconnection of compressed air, gas-free testing per test and issue gas-free certificate, ventilation fans and portable ducting each, and carnage etc [11].

Table 1: Sample Calculation

Ro Ro Ferry		
(1) Shifting of blocks after docking:		
Total man-hours required for berth preparation = 5 + 3 = 8 man-hours		
(2) Dock Services for 10 days:		
Service	Man-hours/day	Total man-hour
Fire and Safety Watchman	24	132
Garbage skip	2	20
Electrical shore power connection and disconnection	4	4
Temporary connection of fire main to ship's system	5	5
Maintaining pressure to ship's fire main	3	30
Sea circulating water connection	3	3
Sea circulating water	4	40
Telephone connection on board ship	3	3
Supply of ballast water per connection	4	4
Supply of fresh water per connection	3	3
Connection and disconnection of compressed air	3	3

Gas-free testing per test and issue of gas free certificate	8	8
Ventilation fans and portable ducting each	5	5
Total man-hour required for 10 days		**260**
(3) Underwater area including boot-top:		
Area = {(2 x draft) + BM} x LPP x P =	591.28	m^2
Boot-top area = {(0.5xBM)+LPP}x2xheight of boot-top =	16.25	m^2
Therefore underwater area =	**575**	$\mathbf{m^2}$
Cost of Sandblasting =	**11500.6**	**BDT**
Topsides area = {LOA+(0.5xBM)}x2xheight of topsides =	317.47	m^2
Bulwarks area = {LOA+(0.5xBM)}x2xheight of bulwarks =	141.25	m^2
Therefore total painting area of ship hull =	**1050**	$\mathbf{m^2}$
Cost for Painting =	**42000.06**	**BDT**
(4) Total man-hour required for removal of rudder for survey =	180	man-hours
(5) Current amps = underwater area* current density/1000 =	8.63	Amp
Total weight of zinc anode = current amp x design life*k/capacity [where k =8760] =	503.73	Kg
Total man-hour required to cut off & replace the zinc anode =	50	man-hours
(6) Man-hour required for staright run =	240	man-hours
Man-hour required for curved =	180	man-hours
Therefore total man-hour required for fender works of 200 mm dia =	420	man-hours
(7) Man-hour required for repairing anchors & cables =	140	man-hours
(8) Total man-hour required for opening, cleaning, painting & other works for two chain lockers =	140	man-hours
Steel works:		
(9) Weight of twelve external shell plates with double curvature =	2.80	metric tonne
Amount of repair works =	3281	man-hours
(10) Weight of fourteen vertical shell plates with single curvature =	4.396	metric tonne
Amount of repair works =	4062	man-hours
(11) Weight of one keel plate with single curvature =	0.17	metric tonne
Amount of repair works =	61	man-hours
(12) Weight of twelve bottom shell plate with double curvature =	2.80	metric tonne
Amount of repair works =	3838	man-hours

(13) Weight of one internal bulkheads =	9.04	metric tonne
Amount of repair works =	4652	man-hours
(14) Weight of two transverse internal T members with double curvature above DB area =	0.75	metric tonne
Amount of repair works =	735	man-hours
(15) Weight of bilge strake =	0.06	metric tonne
Amount of repair works =	22	man-hours
(16) Total steel works required =	**20**	**metric tonne**
(17) Total amount of repair work =	**16650**	**man-hours**
(18) Therefore total repair work including removal, re-fitting and fairing in place =	29970	man-hours
(19) Total man-hour required for 15 m of 8 in schedule 80 double bend and 20m of 6 in schedule 80 steel pipe with 3 branches and 4 bends =	3018	man-hours
(20) Man-hour required for pump room: 9m of 6 in straight copper pipe=	146	man-hours
(21) Man-hours required for pipe works at engine room below floor plate level: 70 m of 3 in schedule 80 straight steel pipe=	**150**	**man-hours**
(22) Man-hours required for fitting of three pipe clamps : 8m of 5 in copper pipe with double branches =	72	man-hours
(23) Estimated total man-hours required=	3386	man-hours
(24) Man-hours required to disconnect and remove cylinder head, piston & piston rings[650 mm cylinder bore] =	**480**	**man-hours**
(25) Man-hours to clean all parts including cylinder cover and cylinder head =	288	man-hours
(26) Man-hours required for withdrawing of cylinder liner and installing of rubber seals =	642	man-hours
(27) Man-hours required for reassembling, calibrating and presenting for survey =	184	man-hours
(28) Installation & resistance test before the repair works =	56	man-hours
After the repair works =	56	man-hours
Total man-hour needed =	112	man-hours
(29) Man-hour required for 5 single speed AC induction electric motors (2x10KW and 3x20KW) =	196	man-hours
(30) Man-hour needed to repair 2 electric motors (40 kw) =	440	man-hours
(31) Man-hour required for one 2 x 45 KVA electric generator =	**150**	**man-hours**
(32) Total man-hour required =	898	man-hours

Table 2: Scope of work : Dock Services

Days required for dock services	Inland Ro Ro Ferry	Inland Passenger Vessel	Inland Oil Tanker	Inland Cargo Vessel	Fishing Vessel	Salvage Vessel	Tugboat
	Estimated Man-hour						
5	130	140	125	120	110	115	105
7	182	196	175	168	154	161	147
10	260	280	250	240	220	230	210
12	320	336	300	288	264	276	252
15	395	420	375	360	330	345	315
Average	257	274	245	235	216	225	206
Standard Deviation(SD)	107	111	99	95	87	91	83

Table 2 shows that man-hour for dock services for 5,7,10,12,15 days vary as per type of vessels like Inland Ro Ro Ferry, Inland Passenger Vessel, Inland Oil Tanker, Inland Cargo Vessel, Fishing Vessel and Tugboat. The average man-hour is calculated based on the man-hour for various assuming days of dock services. Thus the standard deviation is also calculated.

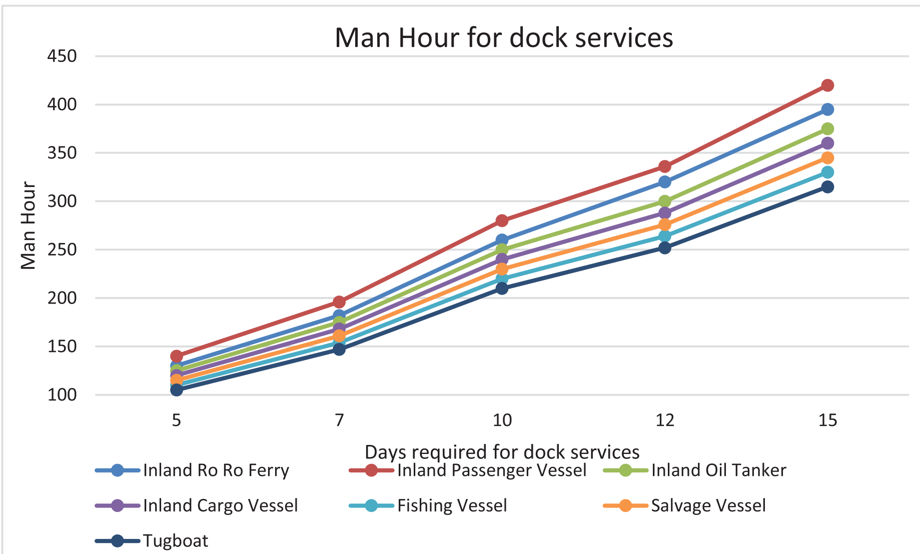

Figure 1 : Dock Services

Figure 1 shows that man-hour varies according to the dock services for different type of vessels.

3.2. Cost for Sandblasting

Underwater area is calculated by using the following formula for different type of vessels to find out the cost of sandblasting.

Area = {(2xdraft) + BM} x LPP x P

Boot-top area = {(0.5 x BM) + LPP} x 2 x height of boot-top

Underwater area = Area + Boot-top area

Different values of draft have been observed for various vessels, resulting in variations in the underwater area. Based on the calculated underwater areas, the tariff charges of different maintenance yards have been multiplied. Thus we have got the cost of sandblasting for various vessels.

Table 3 : Scope of work : Sandblasting

Underwater partial area (m^2)	Inland Ro Ro Ferry	Inland Passenger Vessel	Inland Oil Tanker	Inland Cargo Vessel	Fishing Vessel	Salvage Vessel	Tugboat
	Estimated Cost in BD Taka						
575	11500	14375	13225	12650	10350	10925	9775
600	12000	15000	13800	13200	10800	11400	10200
645	12900	16125	14835	14190	11610	12255	10965
670	13400	16750	15410	14740	12060	12730	11390
700	14000	17500	16100	15400	12600	13300	11900
Average	12760	15950	14674	14036	11484	12122	10846
Standard Deviation(SD)	1016	1270	1169	1118	915	965	863

Table 3 shows that for assuming small portion of the underwater area of various vessels man-hour estimation changes accordingly. As per the local rate schedule of different dockyards the estimated cost of sandblasting varies for different type of vessels.

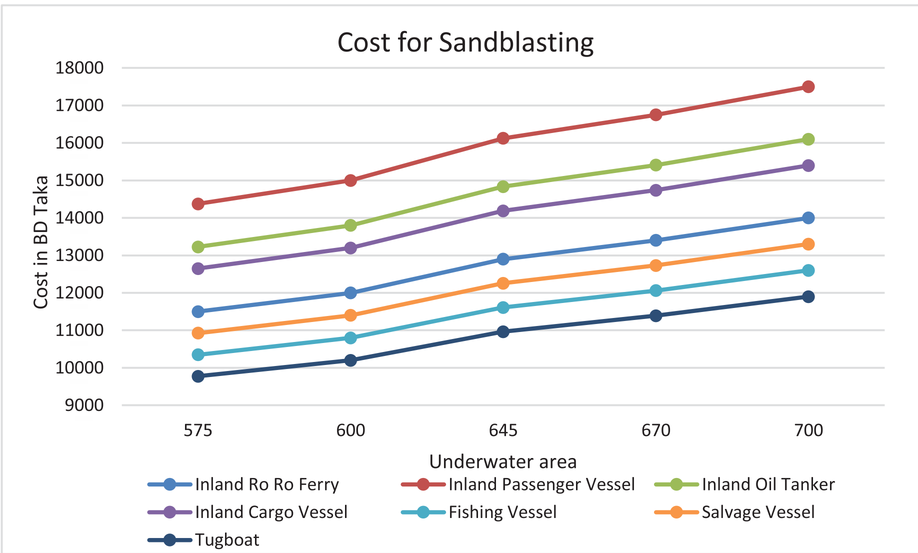

Figure 2 : Sand Blasting

Figure 2 shows that estimated cost for sandblasting varies as per the assumed small portion of underwater area of different vessels.

3.3. Cost for Painting

Total painting area of ship hull is calculated by using the following formula for different type of vessels to find out the cost of painting.

Topside Area = {LOA + (0.5 x BM) x 2 x height of topsides
Bulwarks Area = {LOA + (0.5 x BM) x 2 x height of bulwarks
Total painting area of ship hull = Topside Area + Bulwarks Area
The research has identified varying lengths overall (LOA) for different vessels, leading to differences in the painting area of their ship hulls. By calculating the painting areas of ship hulls, the study multiplied the tariff charges of different maintenance yards to determine the cost of painting for each vessel.

Table 4 : Scope of work (Painting)

Hull area (m^2)	Inland Ro Ro Ferry	Inland Passenger Vessel	Inland Oil Tanker	Inland Cargo Vessel	Fishing Vessel	Salvage Vessel	Tugboat
	Estimated Cost in BD Taka						
1050	42000	47250	45150	44100	39900	40950	38850
1180	47200	53100	50740	49560	44840	46020	43660
1274	50960	57330	54782	53508	48412	49686	47138
1320	52800	59400	56760	55440	50160	51480	48840
1407	56280	63315	60501	59094	53466	54873	52059
Average	49848	56079	53587	52340	47356	48602	46109
Standard Deviation(SD)	5475	6160	5886	5749	5202	5338	5065

Table 4 shows that for assumed hull area of different vessels the estimated man-hour varies and as per the local rate schedule of different dockyards the estimated cost for painting also varies.

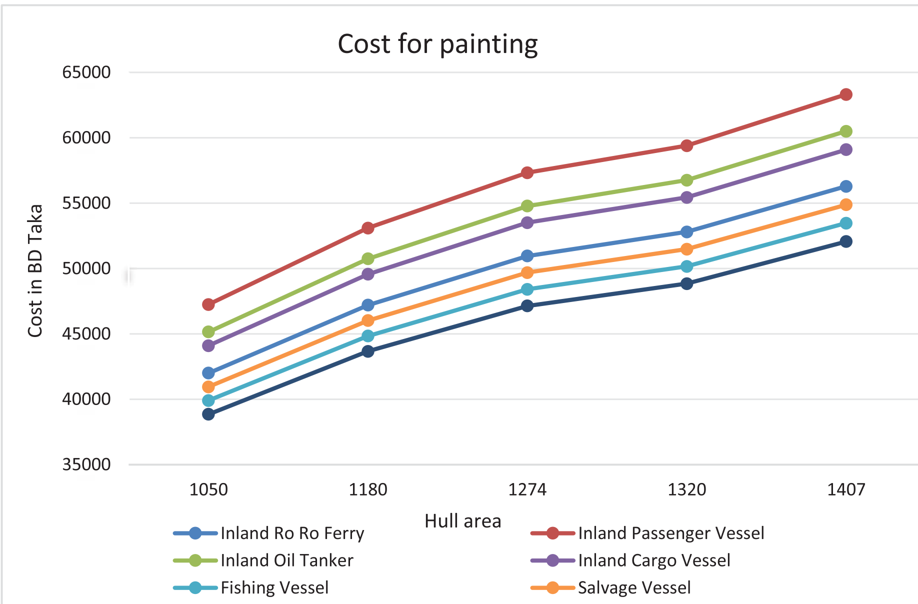

Figure 3 : Painting

Figure 3 shows that estimated cost for painting varies as per the assumed hull area of different vessels.

3.4. Man hour for steel works

Steel works constitute the primary repair and maintenance tasks undertaken by maintenance yards. In this section, the total quantity of steel works is calculated in metric tons, and man-hours are estimated based on the quantity of steel works. The sample calculation involves various thicknesses of M.S Plate with single or double curvature, along with corresponding man-hour estimations as outlined in the following table:

Table 5 : Plate thickness vs man hour.

Plate thickness (mm)	Man-hour per ton
Up to 6	250
8	245
10	240
12.5	230
16	220
18	210
20	200

Table 5 shows that man-hour per ton of MS Plate varies as per the plate thickness up to 20mm and 200 man-hour per ton.

Table 6 : Scope of work : Steel Works

Metric Ton	Inland Ro Ro Ferry	Inland Passenger Vessel	Inland Oil Tanker	Inland Cargo Vessel	Fishing Vessel	Salvage Vessel	Tugboat
	Estimated Man-hour						
20	16500	17400	18000	17900	16800	17000	15800
25	18300	19500	20000	18600	17000	17580	16000
27	22400	24800	23000	22700	22000	23200	22300
30	26840	27500	27000	26900	25800	26000	25130
33	29650	28700	28200	27850	27000	26840	26950
Average	22738	23580	23240	22790	21720	22124	21236
Standard Deviation(SD)	5552	4947	4380	4582	4772	4618	4724

Table 6 shows that for the variation of steel works of 20, 25, 27, 30, 33 metric ton the estimated man hour changes for different type of vessels. Thus the average and standard deviation is calculated as well.

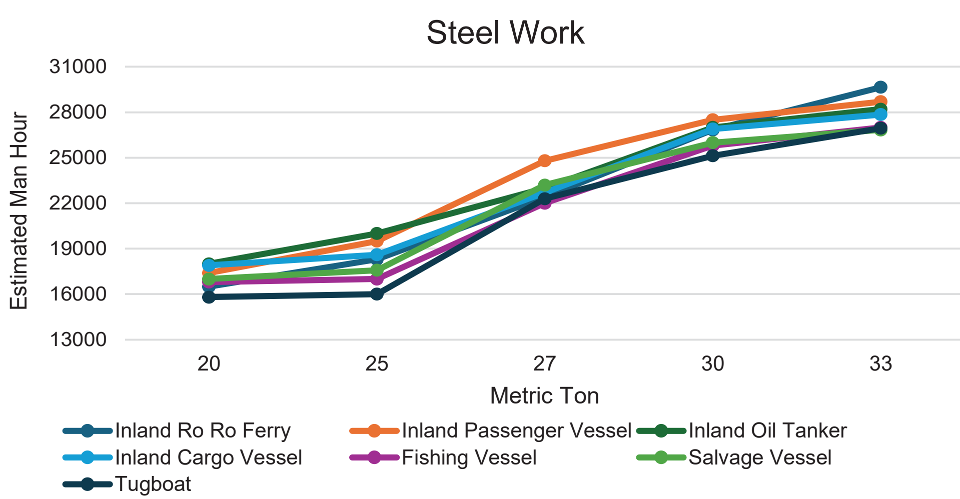

Figure 5 : Steel works.

Figure 5 shows that estimated man-hour changes for steel works in metric ton for different type of vessels.

3.5. Man hour for pipe works

Pipe work is considered as one of the most important maintenance work for the ships. Piping system keeps the ship in service and a ship consists of different types of piping system. Man hour is estimated based on pipe works calculated in meter both for schedule 40 steel straight pipe and schedule 80 steel straight Galvanized and Copper pipes. Man hour varies on the pipe diameter as mentioned in the following table:

Table 7 : Pipe dia. vs man hour

Pipe dia. (inches)	Man hour
>3	2
4	2.5
5	3
6	3.5
8	4
10	5
12	6
14	8
16	9
18	11
20	12
22	13
24	14

Table 7 shows that as per the variation of pipe diameter the man-hour also varies up to 24 inches pipe diameter the man-hour is 14.

Table 8 : Scope of work : Pipe Works

Days required for Pipe Works	Inland Ro Ro Ferry	Inland Passenger Vessel	Inland Oil Tanker	Inland Cargo Vessel	Fishing Vessel	Salvage Vessel	Tugboat
	Estimated Man-hour						
70	150	157	145	144	140	138	135
80	170	185	173	170	160	165	155
100	190	205	200	195	180	185	175
110	200	220	215	205	195	207	188
120	230	245	240	237	220	225	210
Average	188	202	195	190	179	184	173
Standard Deviation(SD)	30	31	37	35	31	34	29

Table 8 shows that for the variation of pipe works for different days the man-hour estimation changes for different type of vessels. Thus the average and standard deviation is calculated as well.

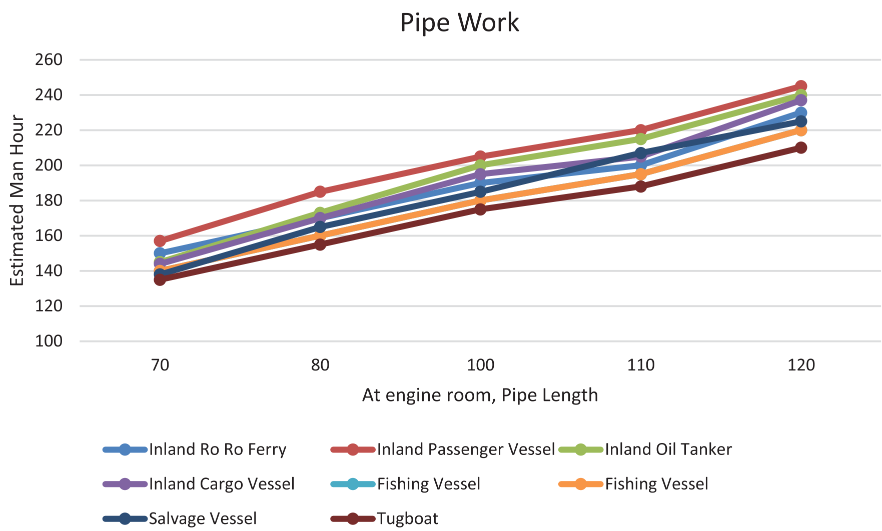

Figure 6 : Pipe works

Figure 6 shows that estimated man-hour changes for the assumed pipe length at the engine room for different type of vessels.

3.6. Man hour for engine overhauling

Man hour has been estimated for engine overhauling work. Top overhaul consists of disconnect and connect cylinder head, withdraw piston, remove piston rings, clean, calibrate and reassemble, installing new spare parts etc. Man hour varies based on the cylinder bore in mm as per the following table:

Table 9 : Cylinder bore vs man hour

Cylinder bore (mm)	Man hour per cylinder
500	60
550	62
600	67
650	72
700	77
750	82
800	90
850	97
900	107
950	120
1000	135

Table 9 shows that for different cylinder bore the man-hour per cylinder varies up to 1000mm cylinder bore the man-hour is 135.

Diverse cylinder bore sizes were observed in 6-cylinder and 8-cylinder engines across various vessels. Specifically, for an inland ro-ro ferry with a 650 mm cylinder bore, 480 man-hours were estimated, whereas for the same vessel type with a 900 mm cylinder bore, 750 man-hours were projected. This illustrates a direct correlation between the number of cylinders and the cylinder bore diameter, resulting in a corresponding increase in man-hours.

Table 10 : Scope of work : Top overhaul of 6 cylinder diesel engine

Cylinder bore (mm)	Inland Ro Ro Ferry	Inland Passenger Vessel	Inland Oil Tanker	Inland Cargo Vessel	Fishing Vessel	Salvage Vessel	Tugboat
	Estimated Man-hour						
650	480	540	460	440	435	438	425
700	522	550	510	490	460	480	445
750	570	590	560	558	550	555	530
850	690	730	680	675	660	667	620
900	750	780	725	710	680	695	660
Average	602	638	587	575	557	567	536
Standard Deviation(SD)	114	110	112	116	111	112	104

Table 10 shows that for the top overhaul of 6 cylinder diesel engine for different cylinder bore like 650mm, 700mm, 750mm, 850mm and 900mm the estimated man-hour changes for different type of vessels. Thus the average and standard deviation is calculated as well.

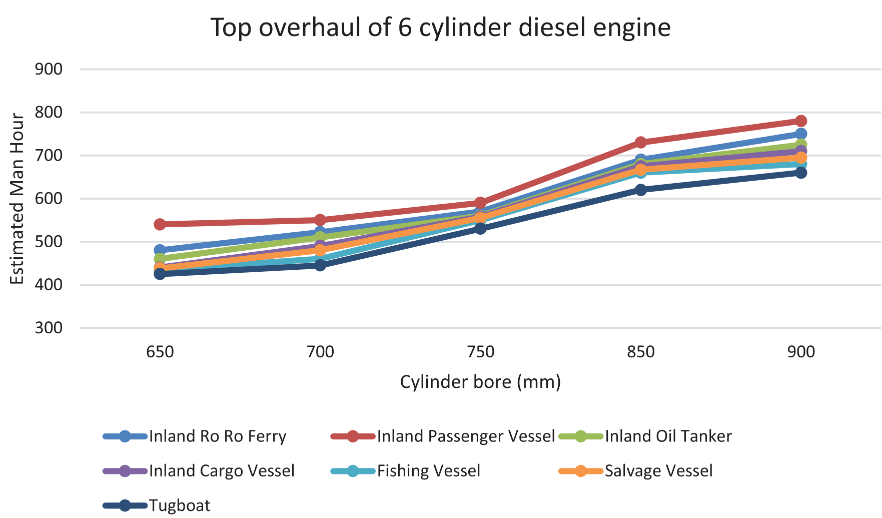

Figure 7 : Top overhaul of engine.

Figure 7 shows that the estimated man-hour changes for top overhaul of engine of different type of vessels.

3.7. Man hour for electrical works

This study examines various electric works required for ships, focusing on electric generators to estimate man-hours for different vessel types. Typically, vessels are equipped with two standby generators and one emergency generator of varying KVA. Man-hour estimation varies according to the following KVA chart:

Table 11 : KVA vs man hour.

KVA	Man hour
<50	75
51-100	90
101-200	100
300	140
400	160
500	175
600	190
750	200
1000	220

Table 11 shows that for different KVA of Generators the man-hour changes like up to 1000KVA the man-hour is 220.

Table 12 : Scope of work : Electrical works for generators

KVA	Inland Ro Ro Ferry	Inland Passenger Vessel	Inland Oil Tanker	Inland Cargo Vessel	Fishing Vessel	Salvage Vessel	Tugboat
	Estimated Man-hour						
2 X 45	150	165	145	140	135	138	124
2 X 75	180	220	210	200	175	178	170
2 X 110	230	245	233	230	228	229	225
2 X 130	265	285	275	273	256	260	245
2 X 145	280	300	288	285	275	283	265
Average	221	243	230	226	214	218	206
Standard Deviation(SD)	55	54	57	59	58	60	57

Table 12 shows that for different KVA of Generators of different vessels the estimated man-hour changes. Thus the average and standard deviation is also calculated.

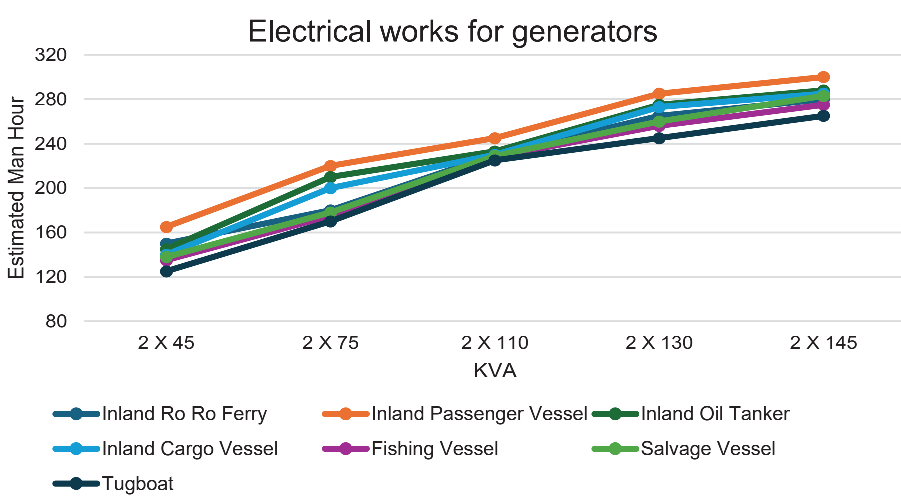

Figure 8 : Electrical works.

Figure 8 shows that for electrical works of different vessels the man-hour estimation changes and is plotted in the graph.

4. Comparative study of cost for different dockyards

For this study, various maintenance yards such as BIWTC, BIWTA, Highspeed Shipyard, and Meghna Shipyard were visited to gather necessary data and information. Additionally, onboard inspections of different vessels including inland ro-ro ferries, inland passenger vessels, inland oil tankers, inland cargo vessels, fishing vessels, salvage vessels, and tugboats were conducted to acquire the requisite information for this study.

The estimated total average man-hours for various types of vessels are as follows: inland ro-ro ferry - 86,617 man-hours, inland passenger vessel - 96,946 man-hours, inland oil tanker - 92,758 man-hours, inland cargo vessel - 90,392 man-hours, fishing vessel - 81,726 man-hours, salvage vessel - 84,042 man-hours, and tugboat - 69,550 man-hours.

Tariff charges and overhead cost at Meghna Shipyard is highest among the other maintenance yards. Whereas the tariff charges and overhead cost at BIWTC Dockyard is the minimum. This is why, the cost of Meghna Shipyard is highest and the cost of BIWTC Dockyard is the lowest.

According to the type of vessels and scope of works the total average man hour also varies. For example, total average man hour for inland ro ro ferry is estimated 86617 for some selected scope of works. This total man hour is considered as the fixed for different maintenance yards and find out different cost summary as the tariff charges and overhead cost.

Table 13 : Analysis of cost at different dockyards

Type of vessels	Total Average MH	Cost at BIWTC Dockyard (BD TK.In Lac)	Cost at BIWTC Dockyard (BD TK.In Lac)	Cost at Highspeed Shipyard (BD Tk. In Lac)	Cost at Meghna Shipyard (BD Tk. In Lac)
Inland Ro Ro Ferry	86617	70.16	73.62	77.96	82.29
Inland Passerger Vessel	96946	78.53	82.40	87.25	92.10
Inland Oil Tanker	92758	75.13	78.84	83.48	88.12
Inland Cargo Vessel	90392	73.22	76.83	81.35	85.87
Fishing Vessel	81726	66.20	69.47	73.55	77.64
Salvage Vessel	84042	68.07	71.44	75.64	79.84
Tugboat	69550	56.34	59.12	62.60	66.07

Table 13 shows that total average man-hour charges for different vessels like Inland Ro Ro Ferry, Inland Passenger Vessel, Inland Oil Tanker, Inland Cargo Vessel, Fishing Vessel, Salvage Vessel and Tugboat. As per the rate schedule of different dockyards cost of docking repair works also varies such as for 86617 average man-hour the repair cost of an Inland Ro Ro Ferry at BIWTC Dockyard is Tk. 70.16 Lac, at BIWTA Dockyard Tk. 73.62 Lac, at High speed Shipyard Tk. 77.96 Lac and at Meghna Shipyard Tk. 82.29 Lac.

5. Case Study

5.1. Case study-1 : Ro Ro Ferry

Repair and maintenance cost for some assumed scope of works for Ro Ro ferry at BIWTC Dockyard is Tk. 70.16 lac, at BIWTA Dockyard is Tk. 73.62 lac, at Highspeed Shipyard is Tk. 77.96 lac and at Meghna Shipyard is Tk. 82.29 lac.

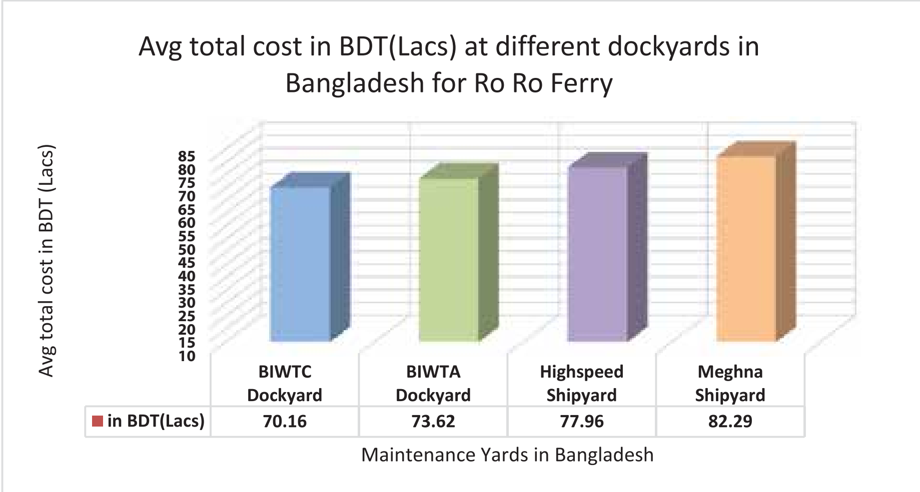

Figure 9 : Ro Ro Ferry.

Figure 9 shows the average total cost for Ro Ro Ferry at different maintenance yards, where the repair cost at BIWTC Dockyard is the lowest in Tk. 70.16 Lac and at Meghna Shipyard the repair cost is the highest in TK. 82.29 Lac.

5.2. Case study-2 : Inland Passenger Vessel

Repair and maintenance cost for some assumed scope of works for Inland Passenger Vessel at BIWTC Dockyard is Tk. 78.53 lac, at BIWTA Dockyard is Tk. 82.40 lac, at Highspeed Shipyard is Tk. 87.25 lac and at Meghna Shipyard is Tk. 92.10 lac.

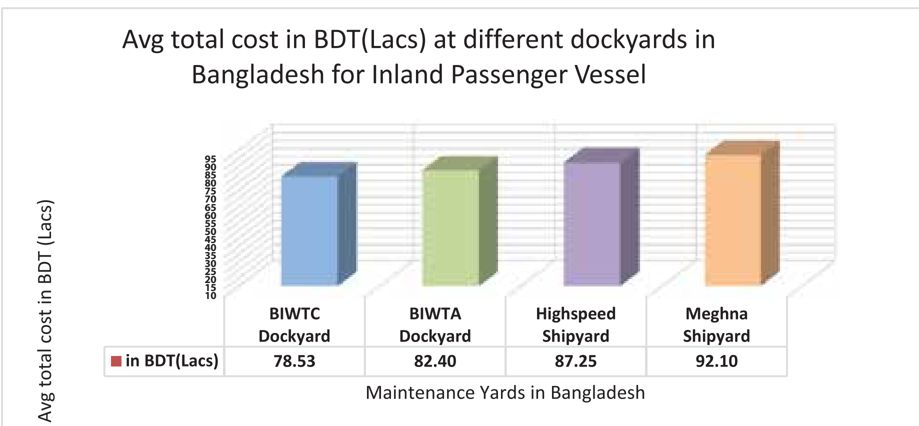

Figure 10 : Inland Passenger Vessel.

Figure 10 shows the average total cost for Inland Passenger Vessel at different maintenance yards, where the repair cost at BIWTC Dockyard is the lowest in Tk. 78.53 Lac and at Meghna Shipyard the repair cost is the highest in TK. 92.10 Lac.

5.3. Case study-3 : Inland Oil Tanker

Repair and maintenance cost for some assumed scope of works for Inland Oil Tanker at BIWTC Dockyard is Tk. 75.13 lac, at BIWTA Dockyard is Tk. 78.84 lac, at Highspeed Shipyard is Tk. 83.48 lac and at Meghna Shipyard is Tk. 88.12 lac.

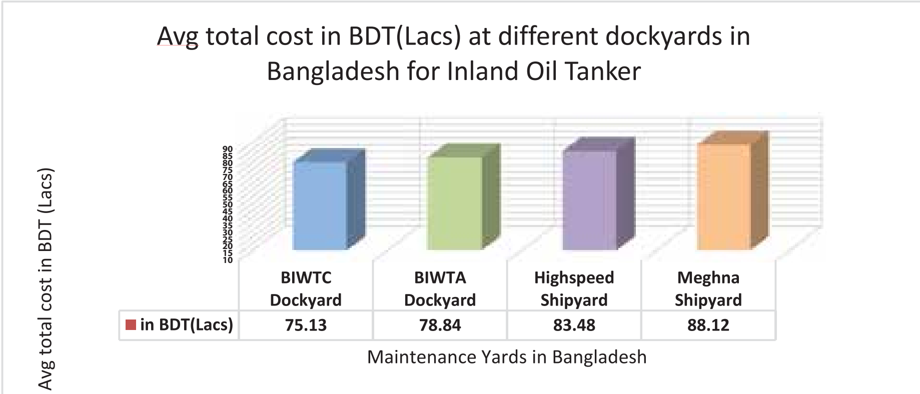

Figure 11 : Inland Oil Tanker.

Figure 11 shows the average total cost for Inland Oil Tanker at different maintenance yards, where the repair cost at BIWTC Dockyard is the lowest in Tk. 75.13 Lac and at Meghna Shipyard the repair cost is the highest in TK. 88.12 Lac.

5.4. Case study-4 : Inland Cargo Vessel

Repair and maintenance cost for some assumed scope of works for Inland Cargo Vessel at BIWTC Dockyard is Tk. 73.22 lac, at BIWTA Dockyard is Tk. 76.83 lac, at Highspeed Shipyard is Tk. 81.35 lac and at Meghna Shipyard is Tk. 85.87 lac.

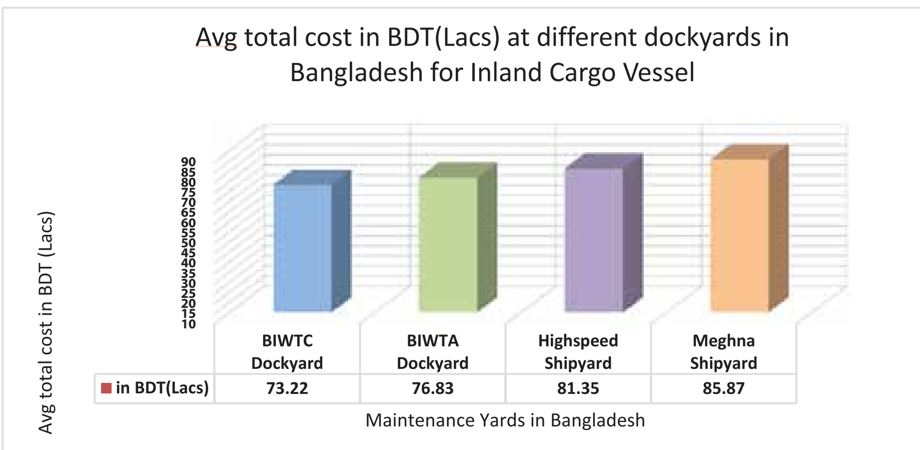

Figure 12 : Inland Cargo Vessel.

Figure 12 shows the average total cost for Inland Cargo Vessel at different maintenance yards, where the repair cost at BIWTC Dockyard is the lowest in Tk. 73.22 Lac and at Meghna Shipyard the repair cost is the highest in TK. 85.87 Lac.

5.5. Case study-5 : Fishing Vessel

Repair and maintenance cost for some assumed scope of works for fishing vessel at BIWTC Dockyard is Tk. 66.20 lac, at BIWTA Dockyard is Tk. 69.47 lac, at Highspeed Shipyard is Tk. 73.55 lac and at Meghna Shipyard is Tk. 77.64 lac.

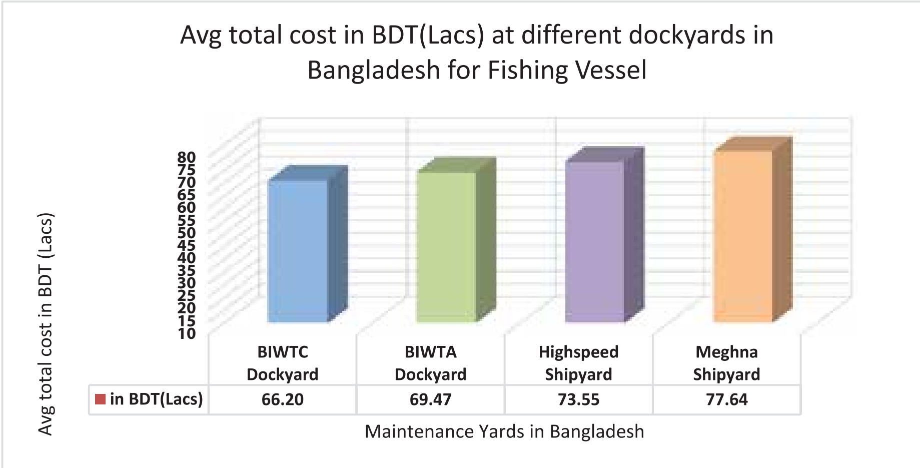

Figure 13 : Fishing Vessel.

Figure 13 shows the average total cost for Fishing Vessel at different maintenance yards, where the repair cost at BIWTC Dockyard is the lowest in Tk. 66.20 Lac and at Meghna Shipyard the repair cost is the highest in TK. 77.64 Lac.

5.6. Case study-6 : Salvage Vessel

Repair and maintenance cost for some assumed scope of works for salvage vessel at BIWTC Dockyard is Tk. 68.07 lac, at BIWTA Dockyard is Tk. 71.44 lac, at Highspeed Shipyard is Tk. 75.64 lac and at Meghna Shipyard is Tk. 79.84 lac.

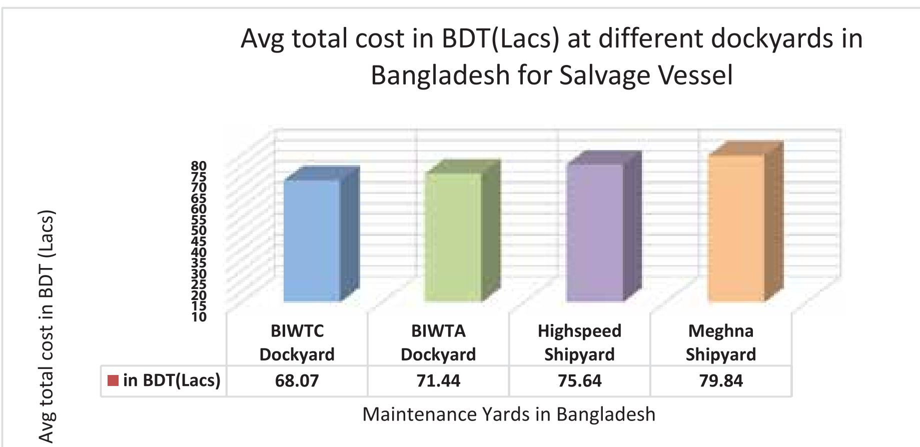

Figure 14 : Salvage Vessel.

Figure 14 shows the average total cost for Salvage Vessel at different maintenance yards, where the repair cost at BIWTC Dockyard is the lowest in Tk. 68.07 Lac and at Meghna Shipyard the repair cost is the highest in TK. 79.84 Lac.

5.7. Case study-7 : Tugboat

Repair and maintenance cost for some assumed scope of works for tugboat at BIWTC Dockyard is Tk. 56.34 lac, at BIWTA Dockyard is Tk. 59.12 lac, at Highspeed Shipyard is Tk. 62.60 lac and at Meghna Shipyard is Tk. 66.07 lac.

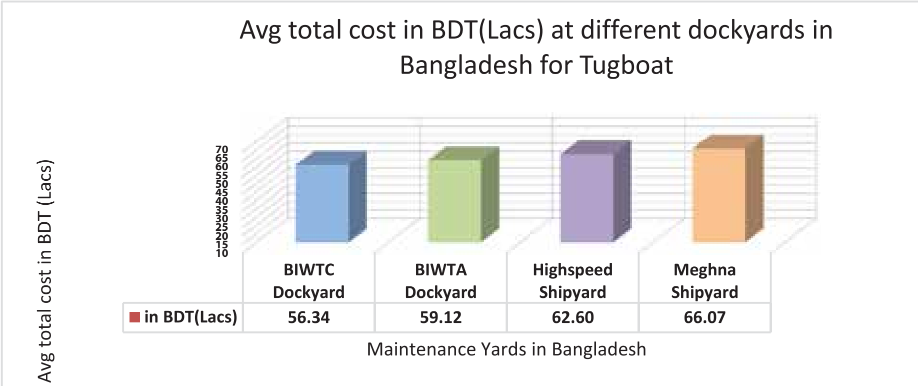

Figure 15 : Tugboat.

Figure 15 shows the average total cost for Tugboat at different maintenance yards, where the repair cost at BIWTC Dockyard is the lowest in Tk. 56.34 Lac and at Meghna Shipyard the repair cost is the highest in TK. 66.07 Lac.

6. Projected average man hour for different vessels and discussion

In calculating the labor man –hours , it is very usual that these will vary for similar jobs carried out at different maintenance yards. Once the calculation of man hour is completed the estimator must apply the pricing rates to find out the cost considering the local economy. Obviously different shipyards have different working conditions and techniques, so the man hours for the work can vary. However, the figures shown can be used as a fair assessment of the work in general and can produce price estimates for budget purposes to a ship owner.

Ship maintenance is a comprehensive service consisting of several activities which reduces costs and extends the life of ship and machineries. There are different types of maintenance works such as preventive or scheduled maintenance system. It is commonly known as PMS or Planned Maintenance System. In this type of system the maintenance works are done as per the designated regulations and running hours like 4000 hrs, 5000 hrs etc. As per the regulation of Department of Shipping, Bangladesh every vessel have to get a docking survey every after 2 years and special docking survey every after 3 years. Another maintenance system is known as corrective or breakdown maintenance. In this system maintenance is carried out when any ship's structure or machineries break down. The other type of maintenance system is called condition maintenance system. In this system the ship surveyor may impose few repair and maintenance conditions for getting the survey registration. For this reason, the ship needs to get these maintenance works at any maintenance yards in order to comply with the Government regulations.

According to the Fortune Business Insights, "The global ship repair and maintenance service market size was valued at USD 34.60 billion in 2022. The market is projected to USD 45.70 billion by 2029." This statistics shows that the ship repair and maintenance sector covers a significant portion of world economy and Bangladesh is also taking her share from this growing sector.

Ship repair and maintenance services can be planned maintenance or unplanned maintenance. This is a crucial part of vessel operations in which the principal elements of vessels that went to be maintained are the ship's hull and structure, engine, electric system, piping system, painting, steel works etc. There are various type of repair docks such as dry docks, floating docks, ship lift, slipway and others. Inland Ro Ro ferries are used to transports cars, buses, trucks and passengers.

These vessels are used to connect the roads by using ship as an alternative of bridge and ensure the connectivity among the whole country. Inland passenger vessels are used to help people to move and communicate from one part of the country to another part. It is also used to carry goods because water transports are considered as the cheaper than the road transports. Inland oil tankers are used to carry imported oil of Bangladesh Petroleum Corporation (BPC) all over the whole country. Inland cargo vessels are playing important role to carry goods from mother vessels of outer anchorage of sea to the harbor and also navigates to the whole country. Fishing vessels are contributing to the country's economy as well as to blue economy by collecting sea fish and marine resources from sea. Salvage vessels are applied in case of any marine accident. These types of vessels are used in emergency incidents to help another vessel. Tugboats are used to toe or guide other vessels in important navigating channels for ensuring the safe navigation. According to the scope of works average man hour for inland passenger vessel is higher because it has large hull area, extended piping systems, accommodation facilities for passengers and crews, different machineries and equipment. Comparing with the other type of vessels Tugboat requires minimum man hour for the repair and maintenance works.

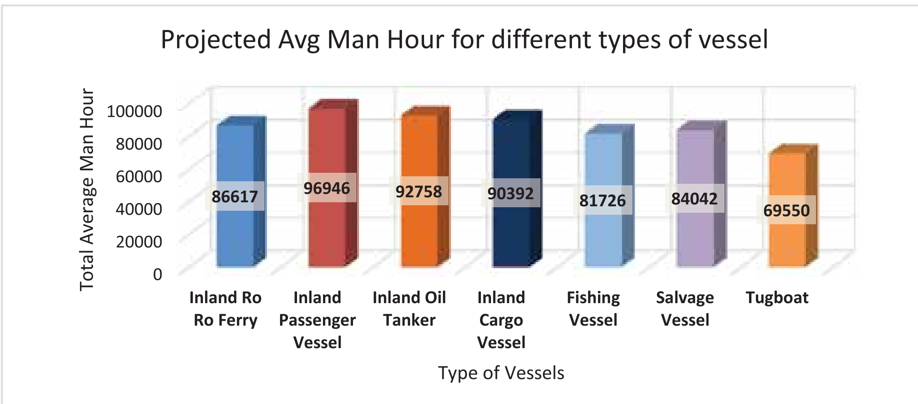

Figure 16 : Projected avg. man hour for different vessels.

Figure 16 shows the projected average man-hour for different vessels at different maintenance yards.

Maintenance yards have their own tariff charges and according to the estimated average man hour total cost for the maintenance works can be find out. Tariff charges varies on the materials cost, equipment facilities, resources, overhead cost and duration of delivery etc. As per the study, the Government maintenance yards take vessel repair cost minimum comparing with the private owned maintenance yards. But these Government organizations also take extended time to deliver the vessel for the bureaucratic appraisal procedures and the lengthy procurement processes. Whereas in the private dockyards, the decision is taken very quickly and procurement process can be completed within the shortest period of time. So they can deliver vessels quickly. Ship owners choose the maintenance yards as per their necessity and requirement. For considering low cost maintenance works ship owners may choose the Government yards and for quicker deliver they choose the private owned yards. If the owners get the vessel quickly or as per the contracted period they can engage these vessels quickly in the traffic for revenue earnings so that they can adjust the maintenance cost and add profit to their annual income statement.

7. Conclusion and Recommendation

Man hour estimation is required to prepare annual maintenance schedule for the maintenance yards and to take cost effective planning for repair and maintenance works of different vessels. Maintenance cost varies according to the maintenance yards tariff charges like docking & undocking charge, slipway rent, berthing charge, overhead cost and materials cost etc. Planned maintenance work can reduce extra time and also can save money. Total work load and available resources to be analyzed before starting any maintenance and have to follow the scheduled planning to avoid the “knock-on effect delays”. To deliver a ship as per the commitment and contract agreement adds values for the maintenance yards as well as to the whole country’s economy. Bangladesh is a major shipbuilding and ship repairing nation, which has a long history. The industry has been growth in recent years when locally made ships began to be exported. Bangladesh has now over 100 shipbuilding companies, mostly concentrated in Dhaka, Chattogram, Narayangonj, Barishal and Khulna. Some of the major shipbuilding and ship repairing companies and organizations are Ananda Shipyard & Slipways Limited, BIWTC Dockyard, BIWTA Floating Dockyard, FMC Dockyard Ltd, Western Marine Shipyard, Chittagong Dry Dock Limited, Khulna Shipyard, Dockyard and Engineering Works Ltd, Highspeed Shipyard, Kornophuli Shipyard, Meghna Shipyard and Three Angle Marine Limited etc. Many people are working in these shipyards and contributing to the GDP growth of the country. The development of shipbuilding and ship repair industry can increase foreign currency earning as like as the garment industry of the country. This industry can be treated as an important economic pillar of the whole nation.

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BLUE ECONOMY IN BANGLADESH: AN OVERVIEW OF POSSIBILITIES, LIMITATIONS, AND CHALLENGES

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ABSTRACT

Bangladesh consists of a vast area of water bodies on which people's livelihoods are highly dependent, which makes the blue economy most vital in the future of Bangladesh. This paper reviews different prospects for the blue economy in Bangladesh, along with its constraints and difficulties, and shows how, if these issues can be resolved, they can accelerate our economic growth. The blue economy in Bangladesh holds immense potential, capitalising on its extensive coastline and abundant marine resources. The sectors of the blue economy that have been emphasised in this paper are renewable energy, fisheries and aquaculture, shipbreaking, coastal and marine tourism, trade and transportation, oil, gas, sea minerals, sea salts, and marine biotechnology. However, challenges like overfishing, pollution, and climate change must be addressed through effective governance and conservation measures to ensure the long-term viability and equitable distribution of benefits from this promising economic sector. Strong law enforcement and sound management are musts for Bangladesh's suitable and sustainable future growth.

Keywords: Bangladesh; Bay of Bengal; Blue Economy; Marine

1. INTRODUCTION

1.1 Ocean

Oceans are essential to the survival of billions of people. They cover more than half of our planet's surface and nearly all of its biosphere. Almost three-quarters of the world's largest cities are located on the coast, and many people live within a few kilometres of the coastline. More than a million individuals work in ocean-related sectors. The majority of trade takes place in the oceans, and a large amount of the world's population relies on them, particularly for food and subsistence. One of the biggest challenges of the 21st century is to give food to 9 billion people by the year 2050 in the context of climate change, financial and economic uncertainty, and increasing competition for natural resources [1]. For the development of food security, livelihoods, and the economy on a global scale, healthy oceans are vital.

1.2 Blue Economy

The ocean has enormous potential for providing sustainable "Blue Energy" through wind, waves, tides, geothermal, and biomass energy sources. Professor Gunter Pauli first proposed the notion of the "Blue Economy" in 1994 [2]. The recent RIO+20 United Nations Conference in Rio de Janeiro, Brazil, on Sustainable Development in June 2012, gave this concept much attention [3]. Blue Economy is defined as all the economic activities associated with oceans, seas, and coasts. According to the European Union (2018), the blue economy includes a wide range of interconnected, established, and growing sectors. An estimation by the OECD (2016) says that the

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global economy receives more than USD 500 billion from ocean-based industries. They also stated that, in 2010, the Blue Economy created about 31 million full-time jobs, accounting for roughly 1% of total employment worldwide.

1.3 Significance of Blue Economy in Bangladesh

Bangladesh holds sovereign rights over an area of 118,813 square kilometres in the Bay of Bengal, according to the International Tribunal for the Law of the Sea (ITLOS) [4]. There are 166,000 square kilometres of water in total, comprising the Exclusive Economic Zone (EEZ). Between 2012 and 2014, issues over Bangladesh's maritime boundary with Myanmar and India were amicably resolved, resulting in the country's territorial waters expanding by more than 30% and receiving the right to 118,813 km^2 in the Bay of Bengal [5]. By 2041, when the 2030 Sustainable Development Agenda has begun, Bangladesh has targeted to become a developed country [6]. For Bangladesh to become a developed country, it's essential to confirm the suitable use of coastal resources in compliance with the laws of nations and to possess a powerful ocean policy. The significance of the blue economic system has led the Bangladeshi government to place excessive precedence on promoting blue growth and accomplishing the Sustainable Development Goals (SDGs). They are working with stakeholders to integrate the blue economy concept into policies and plans. It has been determined that the marine and coastal environments are more important for attaining the country's strategic objectives for economic and social development.

2. The Sectors of Blue Economy

Various sectors are promoting the blue economy at a very promising level as the sustainable growth factor of Bangladesh such as renewable energy, fisheries and aquaculture, shipbreaking, coastal and marine tourism, trade and transportation, oil, gas, sea minerals, and sea salts, as well as marine biotechnology.

2.1 Renewable Energy

2.1.1 Wave Energy

Wave energy is a secondary source of wind energy and solar energy that is plentiful, cost-free, and environmentally friendly. They are a consequence of the water and wind surfaces interacting. The location of energy plant installations is a crucial consideration in the development of wave energy. Deepwater has a higher power concentration than shallow waters; therefore, offshore wave energy harnessing equipment can generate more power than those near the coast. Figure 1 illustrates the influences of wave energy on the surface of the planet.

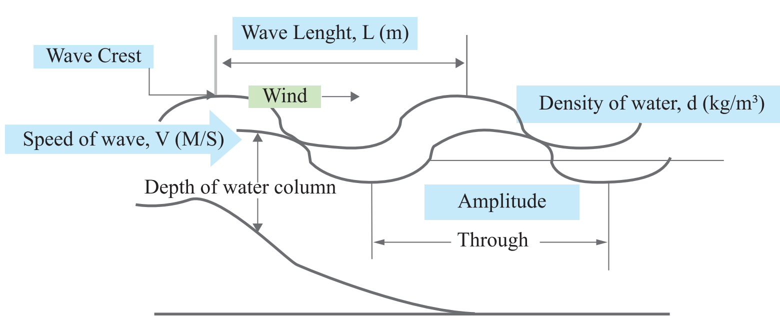

Figure 1 : Factors Affecting Wave Energy Output [7]

The most suitable and potential wave energy harnessing sites in Bangladesh are Hiron Point, Maheskhali Island, Kutubdia Island, Sandwip Island, and the southwest of Cox's Bazar. The wave height along Bangladesh's coastline varies from 1-2 m, depending on the season. The Bay of Bengal's average yearly wave energy density is currently at (8–15) KWm-1, which is considered to be a reduced energy concentration [8]. So, in this region, advanced wave-harnessing technology has to be implemented. Many nations, including the UK, Ireland, Norway, India, and others, have placed orders for OWC (Oscillating Water Column) wave energy harnessing technology [9]. Figure 2 represents the schematic layout of the oscillating water column system.

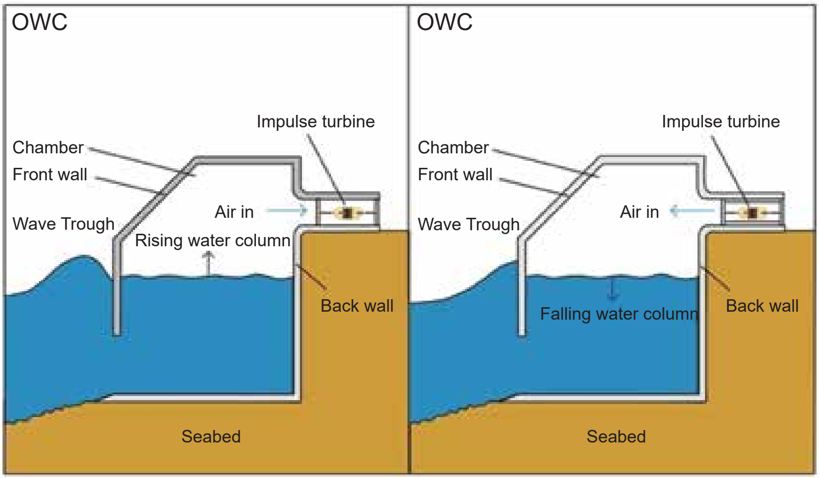

Figure 2 : Schematic Layout of Oscillating Water Column System [10]

2.1.2 Hydropower

Hydropower is also an eco-friendly source of electricity which presently supplies around 20% of the world's electricity. The efficiency of micro-hydro units ranges from about 60% to 90% [11]. Bangladesh's hydropower production capacity in 2014 was 230 MW, which was by Kaptai Hydroelectric [12]. Figure 3 shows a layout of the hydraulic turbine and an electrical generator.

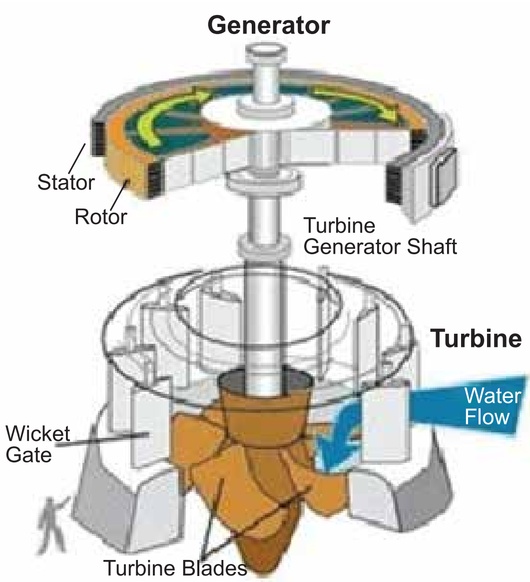

Figure 3 : Hydraulic Turbine and Electrical Generator [12]

According to a recent analysis by the US-based consulting firm STI, also by the Bangladesh Power Development Board (BPDB); Sangu and Matamuhuri river hydropower plants have a combined capacity of 58.33 MW and 75 MW, respectively [13]. Another micro-hydro project, the Mahamaya Irrigation and Hydro Power Project, with a 50–70 kW generation capacity, is being built in Mirsharai, Chittagong [14]. Table 1 lists a few possible small hydro sites that the Bangladesh Power Development Board (BPDB) and Bangladesh Water Development Board (BWDB) have identified.

Table 1: Potential of Micro Hydropower Sites in Bangladesh [15]

District	Potential Areas	Entities Involved
Chattogram	Foy's Lake	4
	Choto Kumira	15
	Hingula Chara	12
	Sealock (Chattogram Hill Tracks)	81
	Lungichara	10
	Budiachara	10
Dinajpur	Dahuk at Burabari	24
	Chawai at U/S of Chawai LLP	32
	Talam at U/S of Talam LLP	24
	Pathraj at Fulbari	32
	Tangaon at D/S of Nargun LLP	48
	Punarbhaba at Singraban	11
Jamalpur	Bhugai-Kongsa at 2 miles U/S. of Nalitabari	69 for 10 months
	Marisi at Dukabad near Jhinaigati	35 for 10 months
Rangpur	Buri Khora Chili at Nizbari	32
	Fulkumar at Raiganj Bazar	48
Sylhet	Nikhari Chara	26
	Madhab Chara 1500 ft from fall	78
	Rangapani Gung	616

2.1.3 Tidal Power

Tidal power also refers to a clean renewable energy source. Tides can be easily produced due to the shifting sea levels and also, they are easier to forecast than wind and sunlight [9]. The tidal stream generator can generate tidal electricity which is therefore anticipated to be much greater than solar and wind energy [16]. The coastal areas with sluice gates and levees, such as Khulna, Satkhira, Barishal, Bagerhat, and Cox's Bazar, are the locations where the low head tidal action can be observed. This tidal range may be readily converted to pollution-free, cleaner, renewable power by using the up-front, low-cost technologies of a "tidal wheel" at the sluice gates [9]. The ISTP of Murdoch University, Australia, is preparing to launch a demonstration tidal power project at Sandwip. A trial paddle wheel will be installed in place of a recently damaged sluice gate as part of an ISTP feasibility plan. If the Sandwip Tide project is a success, it can be implemented in other coastal communities, which will bring fresh energy to the area.

2.2 Fisheries and Aquaculture

2.2.1 Fisheries

A record-breaking 171 million tons of fish were produced worldwide in 2016, with 88% of that quantity going directly into human consumption [17]. Also, almost 60% of the animal protein consumed in Bangladesh comes from fish. About 6.55 lac MT of fish were harvested just from the marine sources of the Bay of Bengal in FY 2017–18 [18]. Table 2 shows the total fish production in Bangladesh in the FY 2020-21 and FY 2010-11.

Table 2: Fish Production Per Fiscal Year (2020-11) and (2010-11) [19]

Fiscal Year	Total Production in Bangladesh (lac MT)
2020-21	46.21
2010-11	30.62

From the data from Table 2, it is clear that the total fish production in Bangladesh has increased at over a 50% rate in the FY 2020-21. In the FY of 2017–18, the export of fish and their products generated 1.5% of the country's foreign exchange profits, provided 2.53% to the agricultural GDP and contributed 3.57% to the national GDP from the fishing industry [18]. The following pie chart in Figure 4 shows the three categories of major fisheries resources in Bangladesh.

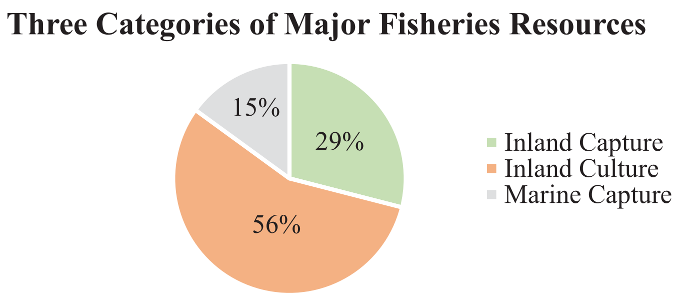

Figure 4 : Three Major Categories of Fisheries Resources [18]

From the figure, it is clear that the inland culture resources hold more than the combined percentage of inland capture and marine capture resources of fisheries. Throughout the decades, the production rate of Hilsha has been higher compared to the combined production rate of Shrimp and Prawns as shown in Figure 5.

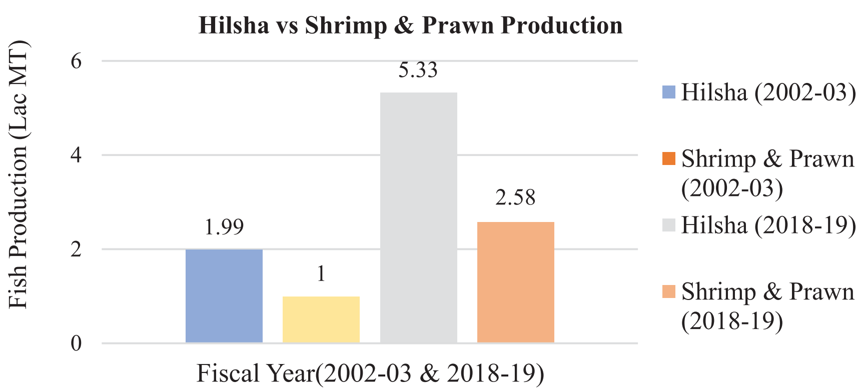

Figure 5 : Hilsha vs Shrimp and Prawn Production [18]

Fish production by different categories (i.e. Inland Open, Inland Close, and Marine) in Previous years has been shown in Table 3 which is represented as a bar graph in Figure 6.

Table 3: Last Few Years Fish Production [18]

Year	Source-Wise Production (Lac MT)			Total (Lac MT)
	Inland Open	Closed	Marine	
2020-2021	13.01	26.39	6.81	46.21
2019-2020	12.48	25.84	6.71	45.03
2018-2019	12.36	24.89	6.6	43.84
2017-2018	12.17	24.05	6.55	42.77
2016-2017	11.64	23.33	6.37	41.34

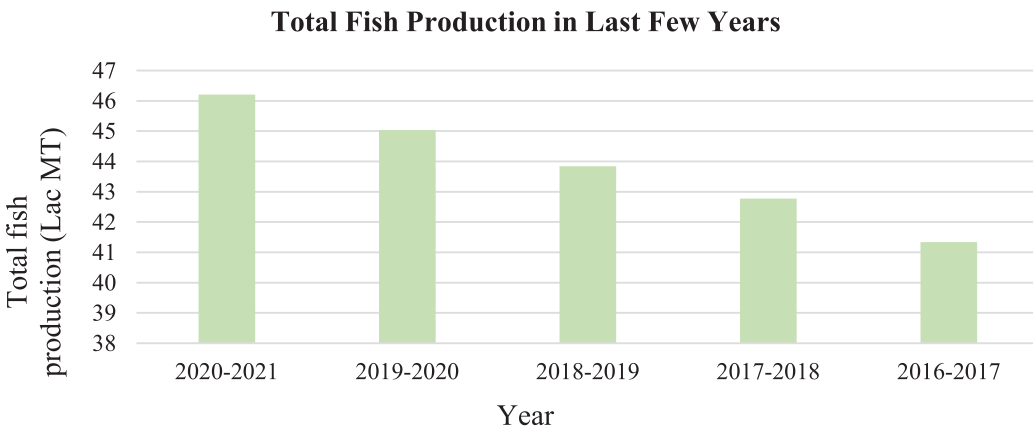

Figure 6 : Total Fish Production in the Last Few Years [18]

47% of the fish consumed by humans today comes from aquaculture, the food industry with the fastest growth in the world. A record-breaking 20.3 kg of fish per capita was consumed in 2016. Global fish exports reached a value of USD 152 billion in 2017 [20]. It was anticipated that fisheries and aquaculture productions would have a combined first-selling value of 362 billion USD, with aquaculture accounting for 232 billion USD of that amount. The government has prioritized the sustainable management of marine fisheries and has taken several actions including designating 698 square kilometres as a marine reserve and 1738 square kilometres as a marine protected area and establishing and maintaining surveillance of these areas in the Bay of Bengal [18]. Table 4 represents the global food fish consumption in per capita terms for the years 1961, 2005 and 2015.

Table 4: Global Food Fish Consumption in Per Capita Terms [21]

Year	Global Food Fish Consumption (Kg)	Average Rate Per Year	Fish Accounted of Animal Protein
1961	9	1.50%	13.70%
2005	16.4		15.3%
2015	20.2		17%

Figure 7 illustrates how major industrial fisheries and small artisanal fisheries contributed to total marine production in 2018–19. The Fisheries Sector in Bangladesh has contributed a lot to the country's GDP in the last few years. Figure 8 shows the contribution of the fisheries sector to the national GDP from 2015 to 2019.

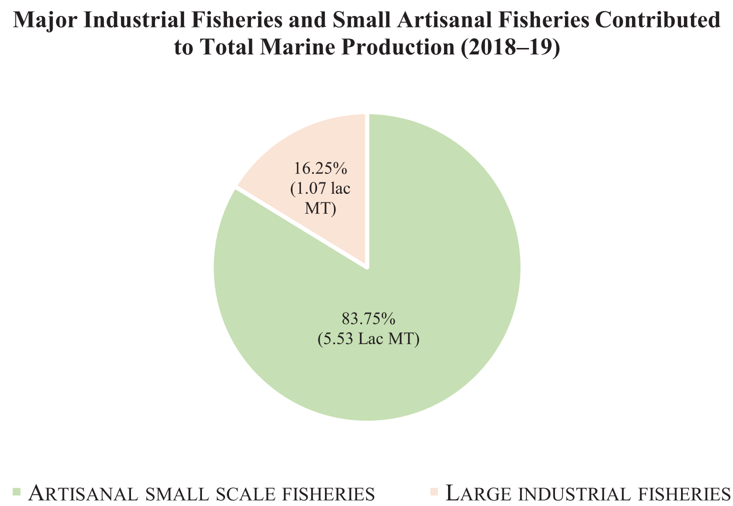

Figure 7 : Contribution to Total Marine Production [18]

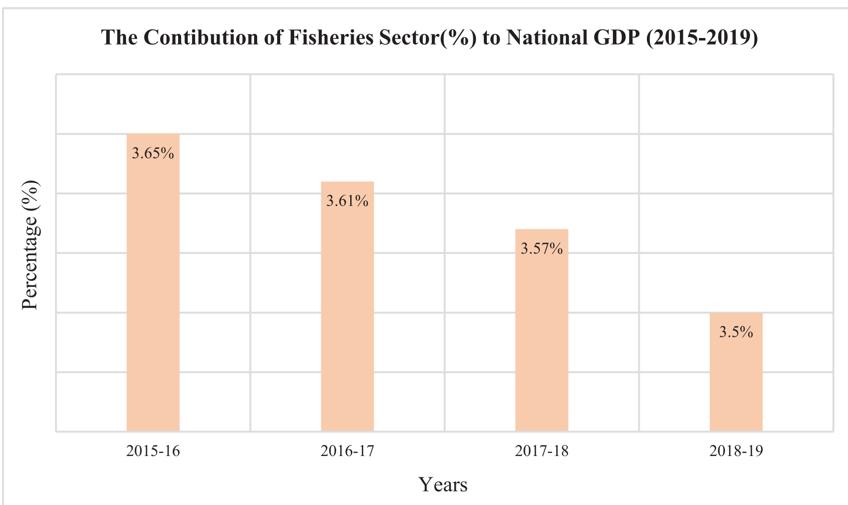

Figure 8 : The Contribution of Fisheries to National GDP [18]

More than 18 million people in the country rely on the overall fishing sector for their livelihoods, both directly and indirectly. The last decade has seen a 53% increase in fish production. The export of fish has also surged by more than 20% [22]. So, in terms of the nation's economic development, this industry offers a lot of promises.

2.2.2 Aquaculture

A tremendously biodiverse aquatic ecosystem and the world's biggest mangrove forest, the Sundarbans, are located along Bangladesh's 710 km coastline in the southwest coastal region. The coastal zone of Bangladesh contains roughly 275,509 acres of shrimp and prawn ghers (modified rice fields). In the Sundarbans, tiger shrimp (Penaeus monodon) are the major product of coastal aquaculture [23].

The gas bladders of C. talabonoides, L. calcarifer, Black mouth croaker (A. nibe), and Indian threadfin (L. indicum) are employed in plastic surgery and the production of clinical thread, which is highly valued on the export market and in high demand. The countries that purchase these fishing byproducts are Thailand, China, and Vietnam [24].

Soft-shell crab is regarded as a delicacy with a high market value, frequently costing up to seven times as much as comparable hard-shell crabs. Only around 10% of coastal land is marginally suitable for crab farming, with 28% of it being highly favourable, 62% being moderately acceptable, and the rest being very suitable [25].

2.3 Ship Breaking

Breaking down ships into their component sections and selling steel, in particular, for scrap, is the process of ship breaking. The primary reason for dismantling a ship is the increase in maintenance costs with age [26]. More than 29,052,000 tonnes of ships were destroyed globally in 2013, of those, 92% took place in Asia. Alang Ship Breaking Yard (India), Chittagong Ship Breaking Yard (Bangladesh), and Gadani Ship-breaking Yard (Pakistan) are the three companies with the largest stakes globally as of January 2020 [27].

Bangladesh has reportedly held the top spot on the global list of shipbreakers for the past few years, according to TBS [28]. An estimated $1.5 billion in annual revenue is produced by Bangladesh's shipbreaking sector [29]. There are currently 160 shipyards in the nation, of which 70–80 are active [30]. An estimated 150 shipbreaking yards are located along the coast to the north of Chittagong, and 50 to 60 of them are open all year. The Chittagong Ship Breaking Yard is situated 20 kilometres (12 miles) northwest of Chittagong in Faujdarhat, Sitakunda Upazila, Bangladesh, near the 18 kilometres (11 miles) Sitakunda coastal strip. In Chittagong, there are 70 enterprises listed as shipbreakers. Additionally, 131 industries are still in their infancy [31].

Each year, around 700 oceangoing ships are scrapped worldwide, and Bangladesh is home to more than 100 of these scrapped ships [29]. 582 ships were scrapped worldwide in the first 3 quarters of 2021 where Bangladesh was a key contributor in this sector. The number of ships that were scrapped in the first 3 quarters of 2021 is shown in Figure 9.

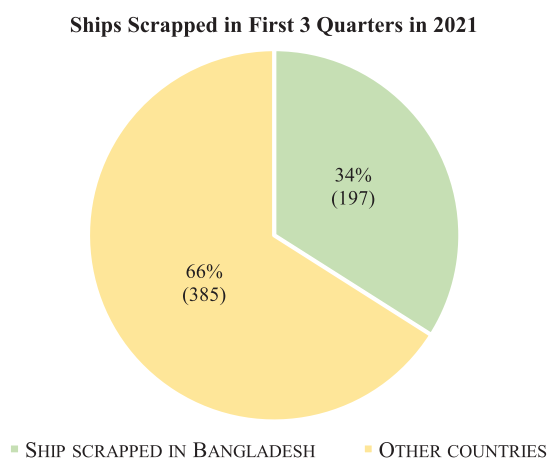

Figure 9 : Ships Scrapped in the First 3 Quarters in 2021 [28]

As about 30% of global shipbreaking activity is concentrated in Bangladesh, 80% of the steel requirements of the country are met through shipbreaking [31]. 350 re-rolling mills receive 60% of the steel produced by the shipbreaking sector [28]. With just the re-rolling mills, billet imports of around 1,181,048 tons can be replaced [31]. Around 20 ships had been scrapped in the 19 operational shipyards as of August 2007, producing over 1,500,000 metric tons of iron. There was a significant increase in imports of scrap ships in 2021, and more than eight million tonnes of metals were collected as a result. Bangladesh is currently the world's top importer of scrap ships, and local shipbreakers demolish 50% of all abandoned ships. Figure 10 shows the number of imported ships for scraping in the last few years [30].

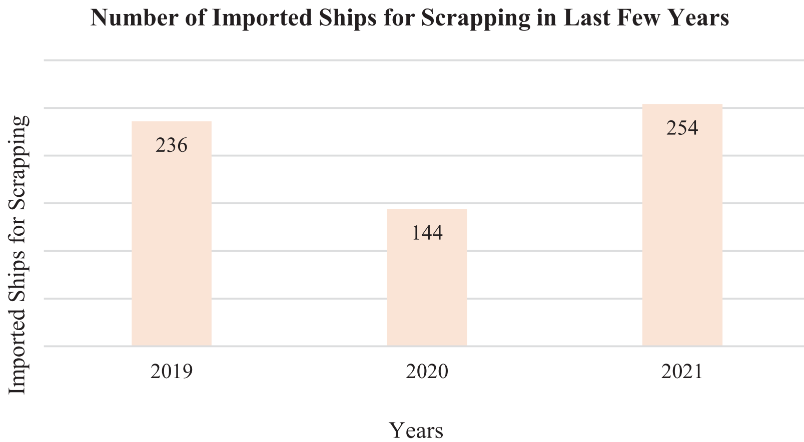

Figure 10 : Number of Imported Ships for Scrapping in the Last Few Years [28]

In 2020, Bangladesh produced about half of the total tons of metal that are produced globally by scrapping ships which is illustrated in Figure 11.

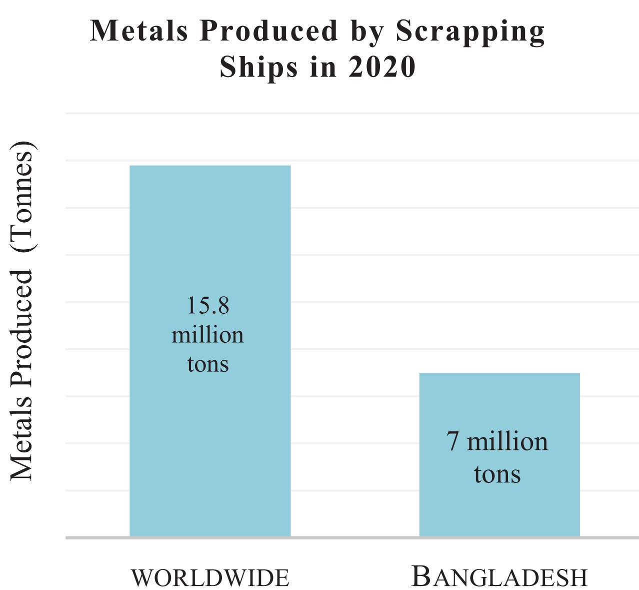

Figure 11 : Metals Produced by Scrapping Ships [28]

In the shipbreaking industries of Bangladesh, the majority of the shipbreaking workers are between the ages of 18-22 years old. Besides this, there is also a big percentage of teenagers working in the shipbreaking yards. Table 5 shows the percentage of shipbreaking workers concerning their ages.

Table 5: Ship Breaking Workers (%) Concerning Their Age [32]

Age Range (Years)	Ship Breaking Workers
18-22	40.75%
46-60	1.13%
Below 18	10.94%

2.4 Coastal and Marine Tourism

Around 80% of all tourism is concentrated in coastal regions [33]. Bangladesh has the world's longest continuous sea beach, measuring 580 km in length, with 200 nm of the exclusive economic zone and 12 nm of territory zone [34]. With a 186 km long, straight, and drivable beach, Cox's Bazar is the coastal tourist centre of Bangladesh [35].

One of the top 25 nations in the world for tourist growth is Bangladesh. According to Lonely Planet, a market leader in publishing travel guidebooks, Bangladesh was placed seventh among the "Top 10 Best Value" travel destinations for 2019 [12]. Since tourism only contributed less than 1% of the country's GDP from 2001 to 2010, compared to 5% of the world's GDP from global coastal tourism, Bangladesh has enormous potential for developing both coastal and marine tourism [36]. The majority of Bangladesh's blue economy's present activities (25%) are related to tourism and recreation [37]. Travel and tourism generated more than 10% of the global GDP in 2019 and supported 333 million employment, one out of every eleven jobs [33]. Figure 13 shows the contribution of travel and tourism to national GDP for previous years.

Figure 12: The Contribution of Tourism and Travel to GDP [38], [39]

A total of 1,326 million foreign tourists arrived in locations around the world, up by almost 86 million from 2016. Thus, total exports from global tourism amount to 1.6 trillion USD, therefore 4 billion USD on average every day [40]. Tourism is a significant global sector; in 2017, international visitor arrivals increased by 7.0%, which was the fastest growth rate since the global economic crisis of 2009. Bangladesh's impact from foreign visitors is still relatively minimal (spending US$333.5 million), making up just 0.7% of all exports in 2019. Only 4% of all travel and tourism expenditures come from foreign travellers. But by 2027, this is probably going to increase by 7.1% annually or 4.7% of the nation's GDP [37].

A partnership-based program called "Sustainable Marine and Coastal Tourism in Bangladesh" (SMCTB) aims to integrate sustainability into Bangladesh's tourism sector. The project was conceived as part of Save Our Sea's "Local is Sustainable" Blue Economy strategy. The idea of creating an Exclusive Tourism Zone (ETZ) in Bangladesh's coastal regions has been impeded in part by a lack of empirical data on potentials and barriers. The goal of the analysis of the growth and promotion of coastal and marine tourism (CMT) was to determine how sustainable CMT can affect the blue economy, create new jobs that will reduce poverty, protect biodiversity, reduce environmental pollution, encourage the sustainable use of coastal and marine resources, support good governance, offer recreational opportunities, and promote ecotourism. On August 27, 2017, a regional workshop titled "Role of Coastal and Marine Tourism on Blue Economic Development in Bangladesh" took place in Chittagong, the goal was to discuss the growth path for coastal and marine tourism in Bangladesh.

The nation provides a variety of locations for the development of ecotourism, archaeological tourism, and historical tourism [36]. The effectiveness with which the difficulties and threats can be resolved will determine how prosperous Bangladesh's marine tourism sector will be [34]. The following figure 14 shows the major threats to coastal and marine tourism.

MAJOR THREATS FOR COASTAL & MARINE TOURISM
Coastal Floods
Rise of Sea Level
Rise of Temperature
Heat Wave
Urbanization
Acidic Sea
Human Waste
Environment Damage

Figure 13: The Major Threats to Coastal and Marine Tourism [36]

2.5 Trade and Transportation

About 80-90% of the world trade is carried out by maritime transportation. In Bangladesh, 90% of the freight commerce is conducted via sea lines. Every year, over 3000 foreign ships that are carrying commodities for Bangladesh worth a total of USD 78 billion (in 2017–18) call on our ports. In 2018, almost 223 million people along with 50 million MT of cargo were transported across inland and coastal networks, leaving potential for future growth and investment along the coastal region [1].

Bangladesh has an extensive inland water transportation network. It contains 21 inland river ports, about 1000 landing places, and a length of about 24,000 kilometres. A container yard with a storage capacity of 3,500 TEUs and 55,000 square meters is located at the Pangoan inland container terminal. Additionally, 116,000 TEUs are handled there annually.

Every year, Chattogram Port handles over 1.5 million TEUs, and eighty per cent of those TEUs arrive in Dhaka via interior waterways [41]. With over 92 % of Bangladesh's EXIM trade passing through Chattogram Port and a growth rate between 15-16%, this port is the most crucial to the country's economic health. According to the Chattogram Port Authority (CPA), the nation's busiest seaport handled 3,097,236 TEUs of cargoes in FY 2020-21, rising from 2,797,190 TEUs in FY 2019–20. The port was listed as the 71st best container port by Lloyd's List [42]. It has improved 40 positions in ten years to be in 58th place overall on the Lloyds list in 2019. Additionally, the amount of freight handled during the current fiscal year was approximately 113.7 million tons [43].

Considering the annual average rates of growth of 15.79% for imports and 15.43% for exports over the previous decade, the predicted transportation value for the following decade would be around USD 435 billion [42]. According to the World Bank Report (2007), the cost to move 1 ton of cargo over 1 km in Bangladesh is roughly Tk. 1, Tk. 2.5 for rail, as well as Tk. 4.5 for roads, and using IWTs instead of roads helps cut down on carbon emissions by about 155,000 tons [44]. Table 6 given below illustrates the comparative position of different modes of trade.

Table 6: Comparative Position of Different Modes of Trade

Modes of Trade	Road	Maritime	Inland Water Transport (IWT)
Comparative Advantage	1. Flexibility 2. Suitable for small parcel 3. Time	1. Low cost 2. Environment Friendly 3. Safe	1. Low cost 2. Environmentally friendly 3. Flexible compared to Maritime 4. Low maintenance cost 5. Greater connectivity 6. Introduction of liner service 7. Safe 8. Institutional arrangement 9. Trade Pattern 10. Initiation of different development schemes
Comparative Disadvantage	1. Expensive 2. Pollution	Slow steaming	1. Slow steaming 2. Awareness 3. Lack of Service Provider

According to research, the IWT system in Bangladesh receives an average allocation of 5% of the entire budget for growth of the surface transportation sector (BIWTA Officials) [44]. A few significant river locations serve as the focal points for Bangladesh's important inland waterways. These cities are Chattogram, Chandpur, Khulna, Narayanganj, Bhairab, and Barishal. That's why in Sonadia, Matarbari, and Payra, numerous port projects are in progress. For our economy to grow, port connectivity must be maintained.

2.6 Oil, Gas, Sea Minerals and Sea Salts

2.6.1 Oil and Gas

Bangladesh is ranked as Asia's 19th-largest natural gas producer [6]. The country has discovered a total of 26 TCF (trillion cubic feet) of gas reserves, of which only 1 TCF is located offshore [1]. Despite having a limited evaluation of its offshore oil and gas potential, Bangladesh drilled 20 wells in the BoB's offshore regions, but only two (Sangu and Kutubdia) were successful in producing gas [20].

Following territorial gains, Bangladesh gained control of 8 in 10 gas blocks that had previously belonged to India and 13 from Myanmar. The amount of gas that can be extracted from these blocks is approximately 40 trillion cubic feet [22]. Geologists believe that Bangladesh may have large gas and oil deposits near the maritime boundary, comparable to those of India and Myanmar. There may be opportunities to obtain significant oil and gas reserves close to Myanmar's Arakan offshore blocks. By 2025, offshore fields are anticipated to produce 34% more crude oil than onshore fields, which produced 32% of the world's crude oil in 2009, with projections indicating even higher production rates thereafter [6].

2.6.2 Sea Minerals

Bangladesh's coastal region, spanning approximately 250 km from Patenga to Teknaf, is home to a variety of sands in hues ranging from dark brown to silvery white. These sands contain valuable heavy minerals [17]. Notably, seventeen deposits of potentially valuable minerals, including zircon, rutile, ilmenite, leucoxene, kyanite, garnet, magnetite, and monazite, have been identified in this coastal area. Updating the 1994 potential evaluation is crucial to speed up the chances for mineral mining under the blue economy [20].

The percentage of global minerals expected to reach the ocean floor was projected to rise to 10% by 2030, with 5% having reached by 2020. Annual global mineral mining is anticipated to increase from nearly nothing to €5 billion during the next decade, and from there to €10 billion by 2030 [6]. The seabed is a valuable hidden resource that today accounts for 32% of the world's hydrocarbon supply, up from 20% in 1980. The ocean floor is being researched and mined for methane hydrates, which can potentially be a huge supply of hydrocarbons.

2.6.3 Sea Salts

Sea salt has been traditionally manufactured along Bangladesh's Cox's Bazar coast for generations [17]. However, despite its significant potential, most salt farms remain small-scale operations where farmers lease the land from landowners and use simple fencing to confine incoming saltwater [45].

Additionally, the rate of salt production is reduced due to ocean pollution, sea level rise, and the deterioration of coastal areas [20]. During a prolonged dry season, salt producers can produce roughly 20 tons per hectare [17]. The average amount of crude salt produced in Bangladesh is between 7000 and 10,000 kg/ha [20]. The Cox's Bazar coastal region produces 22MT of salt annually [17]. Salt production could be a valuable renewable resource in Bangladesh if modern technologies are introduced, and common salt is mined, and refined [20].

2.7 Marine Biotechnology

Marine biotechnology has the opportunity to resolve several global issues, including environmental remediation, energy supplies, sustainable food sources, and human health. It can offer bio-sourced goods such as coatings having anti-fouling or anticorrosive characteristics for shipbuilding and maritime. Blue biotechnology may also help in the creation of particular biopolymers and biomembranes that improve the overall effectiveness of the desalination process. Marine bioresources (main, co-product, and by-products) can be converted into food, medicine, animal feed, and associated bio-based products including cosmetics, nutraceuticals, enzymes, agrichemicals, etc. This could assist Bangladesh to meet its future challenges in the twenty-first century [46]. By 2017, it is anticipated that the worldwide economy for marine biotechnology

goods and procedures will reach US$ 4.6 billion. The market is now estimated to be worth US$ 2.8 billion [47].
For the underwater environment, which is largely unknown and understudied, gene sequencing techniques for live animals are crucial indicators to offer input for the blue economy. Potential medicines can be found in abundance in marine microbes. More than 36 medications derived from marine sources were in clinical development in 2011, with 15 of them being used to treat cancer. The discovery of new antibiotics is such an area where marine biotechnology may have a significant impact. Biostimulation can also be utilized to promote bioremediation following significant pollution to protect natural ecosystems. Using bioremediation to clean up oil spills is another illustration.

3. Key Prospects

The enlarged marine limits have given Bangladesh the chance to investigate the natural resources that are found on land, in water, on the ocean floor, and below the seabed.

- In Bangladesh, marine lines account for around 90% of all freight traffic. Every year, roughly 3000 foreign ships come to our ports with cargo worth a total of USD 78 billion (according to an analysis in 2017–18). Consequently, it is necessary to extensively activate all of the ports available in Bangladesh.
- Several sites exist for the generation of wave energy, including Saint Martin, the Hiron Point, Maheskhali, Kutubdia, Sandwip, and the southwest of Cox's Bazar that are the most suitable and promising wave energy production sites for the installation of OWC and Pelamis' device, which are the most suitable technologies where the wave power density is ideal for practical operation in Bangladesh.
- The Department of Fisheries' analysis indicates that starting in 2016, the annual rate of fish production has been rising steadily over the past few years. Furthermore, since 2016, the fisheries sector has consistently contributed around 3.5% to the country's GDP, which is a respectable amount.
- Around 80% of all travel is associated with tourism in coastal regions. Travel and tourism have continuously contributed 4.5% of the nation's GDP since 2010. Bangladesh offers great potential for the development of marine and coastal tourism.
- Bangladesh is home to more than 100 of the 700 oceangoing ships that are scrapped each year worldwide. Bangladesh accounts for almost 30% of all shipbreaking worldwide. Bangladesh's shipbreaking industry generates an estimated $1.5 billion in annual revenue which provides a great contribution to the annual growth of the National GDP.
- Tiger shrimp (Penaeus monodon), which are mostly produced in coastal aquaculture in Bangladesh's Sundarbans region (57). The gas bladders of C. talabonoides, L. calcarifer, Black mouth croaker (A. nibe), and Indian threadfin (L. indicum) are used in plastic surgery and the creation of clinical thread, which is highly valued on the export market and in high demand.
- It has been discovered that 17 deposits of potentially valuable minerals have been found over the entire coastal region. So, the mineral mining should be continued a regular intervals.
- The global market for marine biotechnology products and processes is predicted to reach US$ 4.6 billion by 2017. The market is currently valued at US$ 2.8 billion. So, Bangladesh should focus on this sector to overcome future economic challenges.

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4. Challenges and Limitations

- A few obstacles stand in the way of the blue economy approach, including recurrent flooding, ocean acidification and blue carbon pollution, a lack of educated staff, the inability to harmonize sectoral policies, plans, and laws, and weak ocean governance.
- Bangladesh grapples with significant hurdles in its renewable energy endeavours. Land scarcity restricts the feasibility of large-scale projects. Securing investments for essential infrastructure like power plants and transmission lines remains challenging, particularly for smaller initiatives. Developing and maintaining renewable systems demands specialized skills, necessitating comprehensive training programs. Integrating variable renewable sources into the grid poses complexities for ensuring stable operations. Additionally, striking a balance between energy needs and environmental preservation requires meticulous assessments to minimize ecological harm, presenting a formidable challenge to sustainability efforts.
- Artisanal fishermen catch small and large marine fish in shallow coastal areas with a variety of net designs and unrestricted mesh sizes. Sell all of these to local buyers as waste fish, which will be utilized as raw materials for fish and poultry feed. The relevant ministries and departments have yet to develop any regulations or enforcement processes addressing these issues. As a result, marine fish diversity is quickly decreasing.
- The ship-breaking sector faces environmental hazards, safety risks, and health concerns due to improper disposal of hazardous materials and poor working conditions. Regulatory compliance, labour rights issues, technological obsolescence, and market instability further compound the challenges of ensuring safe and sustainable operations.
- The marine biotechnology sector faces hurdles, including inadequate infrastructure and funding, limited expertise, and weak regulations. Climate change impacts and pollution strain coastal ecosystems, necessitating bioremediation efforts. Overexploitation and habitat loss hinder biodiversity management.
- The trade and transportation sectors encounter inadequate infrastructure, inefficient logistics, congestion at ports, bureaucratic hurdles, corruption, and vulnerability to natural disasters. These issues hinder economic growth, increase costs, and impede the country's competitiveness in the global market. It can be challenging to guarantee the entire coastal region's sovereignty, maintain security in the economic zone, build environmentally friendly marine infrastructure for sea tourism, and protect the infrastructure of coastal areas from international smugglers, drug traffickers, human traffickers, and pirates.
- There hasn't been any straightforward planning done in Bangladesh to identify and create particular Marine Protected Areas (MPA) or to start using marine biotechnology.
- The challenges for Bangladesh's blue economy include ensuring the sustainable use of biodiversity, sustaining the marine and coastal ecology, protecting mangroves and sea grass, addressing climate change and managing carbon emissions, resolving ocean acidification, and more.
- Additionally, uncontrolled salt manufacturing in Kutubdia and other parts of Cox's Bazar is harmful to the environment.
- For some of the world's poorest people, the overuse and careless handling of coastal resources has also led to missed chances, rising food insecurity, and reduced economic opportunities.

5. Recommendations

- The coastal and marine tourism industry of Bangladesh requires infrastructure development, environmental preservation, marketing campaigns, regulatory frameworks, diversity, partnerships between local communities, businesses, and the government, and proper research and monitoring.
- Implementing renewable energy in Bangladesh demands a multi-faceted strategy: clear policies to attract investment, collaboration with private and international entities, workforce training, community education, smart grid adoption for efficient management, and environmental assessments to balance energy needs with ecological preservation.
- The fishing and aquaculture industries in Bangladesh need to embrace sustainable practices, implement technology and research, development of market infrastructure and industrial plans including the climate change adaption method.
- The shipbreaking industry of Bangladesh has faced criticism for its environmental and safety standards. Therefore, introducing more sustainable practices to mitigate environmental risks improving the safety of workers, and developing modern infrastructure with safe facilities for the shipbreaking industry can enhance the efficiency of the industry, attracting businessmen for more investment.
- Bangladesh can enhance its port infrastructure while managing marine traffic to avoid collisions and ensure smooth trading. Besides, an amount of investment is required for such development including inland waterways.
- Addressing obstacles in Bangladesh's marine biotechnology entails investing in research and infrastructure, enhancing capacity via education and training, and establishing strong regulatory structures. It's essential to implement climate-resilient aquaculture methods, control pollution, and restore habitats. Sustainable management, incorporating eco-friendly technologies, is crucial. Facilitating market access through local business support and technology exchange is pivotal. These approaches enable Bangladesh to tap into its marine resources, promoting sustainable growth and resilience amidst environmental and economic adversities.
- Strengthening policy and regulations can help not only in sustainable eco-tourism but also preserve the marine resources of the mangrove forest. Ensuring sustainable use and farming of mangrove marine resources (e.g. shrimps, soft-shell crabs), and waste products of fishes that are used for plastic surgery and clinical threads not only improves the export rate but also the quality of life of local people. Eco-tourism can also contribute to the ship-building industry by building eco-tourist vessels which will strengthen the overall ship industry.

6. Conclusion

The blue economy presents auspicious prospects for Bangladesh, leveraging its extensive coastline and marine resources for sustainable development. Considering the limitations, and challenges that Bangladesh faces in the blue economy, there is great potential to strengthen it and contribute hugely to enhancing our GDP. Fisheries, maritime trade, tourism, and renewable energy offer avenues for economic growth and job creation. As suitable and promising sites for wave energy production exist, emphasis should be given to this sector. Analyzing the present status of Bangladesh, it is not possible to rely on gas or oil for electricity production. Therefore, renewable energy gives new hope to overcome the present crisis in Bangladesh. Fisheries and aquaculture are already contributing a lot to our economy, but improving the infrastructure can add a new strength to it. More secured and clean scrapping facilities should be maintained in shipbreaking to promote business. Enhancement and enforcement of laws to restrict drug trafficking, and smuggling, along with controlling human waste and environmental damage, should be ensured to attract tourists to our tourist spots. Other ports in Bangladesh, besides Chittagong Port, should be activated widely to reduce freight traffic. As the world's largest mangrove forest is located in Bangladesh, there is a high possibility of flourishing soft-shell crab production, resulting in a high export rate. Marine bioresources can contribute a lot as a remedy for significant pollution, like oil spills in the ocean. There is also a high possibility of using these bioresources as food, chemicals, medicine, and so on to have positive growth in annual economic revenue. However, challenges loom large, including overfishing, pollution, and vulnerability to climate change impacts like sea-level rise and extreme weather events. Limited infrastructure, technological capabilities, and regulatory frameworks pose additional hurdles. Moreover, equitable distribution of benefits and conservation of marine ecosystems are imperative. Addressing these challenges requires comprehensive strategies, investments in infrastructure and technology, international collaboration, and effective governance to ensure the blue economy's long-term viability and contribution to national development. So, to keep pace with the other maritime nations, Bangladesh should keep improving the sectors that lead the blue economy to the sustainable development approach of the country.

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ENVIRONMENTAL IMPACTS OF DREDGING ON ECOSYSTEM, BIODIVERSITY AND SOCIAL LIFE IN BANGLADESH

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ABSTRACT

Dredging is a scientific process to remove sediment and debris from the bottom of the water bodies in order to maintain and develop the waterways, ports and coastal areas for supporting various economic sectors and improving transportation facilities. Dredging has become a significant environmental concern in Bangladesh. This South Asian country is known by its extensive network of rivers and fertile deltas. Consequently, Bangladesh relies heavily on its water resources for livelihoods, agriculture and transportation. However, the environmental impacts of dredging in Bangladesh are multidimensional. It affects the overall ecosystem, biodiversity and also the social fabric of communities living along these water bodies. This article focuses on the environmental and social consequences of dredging in Bangladesh by highlighting the need for comprehensive strategies to mitigate these impacts and safeguard river ecosystems and community well-being.

Keywords: Dredging; Bangladesh; environmental impacts; social impacts; river ecosystems; community livelihoods

1. INTRODUCTION

Bangladesh has an interconnected network of over 700 rivers flowing throughout it like the webs of a spider. Consequently, it relies heavily on its water resources for agriculture, fisheries and transportation. The fertile alluvial soils deposited due to these rivers make Bangladesh one of the most agriculturally productive regions in the world. To sum up, the rivers serve as crucial transportation routes in such rural areas where road infrastructure is insufficient. In order to maintain the navigability of these waterways, dredging has become a frequent activity in our country. But, unfortunately, it has significant environmental and social repercussions. The river ecosystems of Bangladesh are vital to the livelihoods of millions of its people. The rich biodiversity in these river systems contributes to the ecological balance of the region. However, the ongoing dredging activities pose a threat to these critical ecosystems and the communities that depend on them. Especially the unplanned, unscientific and illegal dredging activities are solely responsible for such threats.

Figure 1: Dredging operations at riverbeds of Jamuna river in Bangladesh [5].

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2. Dredging and its Uses

Dredging is the excavation process of the sediments from the bottom of harbors, rivers, lakes and other water bodies. It is carried out mainly to serve 2 purposes. Firstly, to increase the depth of waterways to accommodate commercial and passenger vessels. And secondly, to protect the environment from deposited toxins [1].

2.1.1. Increasing Depth of Waterways to Accommodate the Commercial and Passenger Vessels:

Dredging is a routine necessity worldwide because the natural downstream flow of sand, silt and other particles gradually fills and blocks the channels and berthing areas critical for navigation and maritime trade. Dredging primarily focuses on maintaining or increasing the depth of waterways for safe navigation by commercial and passenger vessels. The larger vessels like container ships and oil tankers are crucial for global trade. As a result, it makes dredging indispensable in order to ensure that the shipping lanes and harbors are deep enough to accommodate them [1].

2.1.2. Environmental Remediation from Deposited Toxins:

Contaminated sediments containing industrial pollutants and municipal sewage discharges often accumulate in harbors and other industrialized water bodies. Dredging removes and isolates these harmful sediments from open water disposal, reducing the risk of ecological and human exposure to persistent toxins concentrated at the bottom of polluted sites [1].

3. Related Work

Every year million tons of sand and soil materials are collected through dredging river bed in Bangladesh . Hydraulic and suction type of dredging is found cheaper and easier to transport. That's why ,it is widely used. But, locally developed dredger and unscientific methods of dredging are used at many places. Despite having some positive effects of dredging like increasing navigational capabilities, it has negative consequences too. The negative impacts may be both short and long term depending on various factors. Dredging not only causes vertical instability in the channel bed but also causes lateral instability in the form of accelerated stream bank erosion and channel widening. In Bangladesh, dredging operations are mainly conducted for 2 reasons. These are - sand and soil materials collection and depth increment of waterways in ports and waterways. [2] At different times, dredging tests were conducted on the main river beds of Bangladesh in order to study the effects of those on the environment. The obtained results of 3 different case studies of dredging at Payra River, Jamuna River and Passur River are discussed briefly.

3.1.1. Payra River

The hydrodynamic changes of Payra river channel were studied before and after dredging by collecting data of different parameters of Payra river bed from its four nearest sandbars . It was found that the dredging of Sandbar-2 created direct influence on bank erosion. It was because the proper methods and scientific techniques were not implemented and the hydrodynamic changes were not taken into considerations. Though the bank erosion decreases as the distance of dredging location increases, still it will have the control to change the geological and also the morphological nature of the river that may disturb the stability of land. Hence there arises the requirement of controlled dredging with regular monitoring. It is because the rest 3 sandbars had no or minimum effects of dredging as a result of implementation of proper scientific dredging techniques [2].

3.1.2. Jamuna River

Specifically 9 points in five cross sections in the Jamuna river were selected for the data collection and analysis regarding dredging activities. The water depth, flow velocity and sediment concentration relationships were utilized in a numerical framework to explore the fluvial geomorphological characteristics. Model outputs anticipated the potential erosion and sedimentation phenomenon at distinct sections which were parallel with the observational field data. However, the persisting impact of dredging was insignificant to the change in river cross-sections. Cross-sectional data from field measurement indicated that the channel near the Sirajganj Hardpoint shifts towards East (left) and the existing channel near the Sirajganj Hardpoint was silted up within a year of monsoon flooding which proves that the impact of dredging was insignificant. It was also observed that the sediment concentration was higher where the dredging alignment crossed through the existing sandbar/char. These phenomena governed due to the hydraulic condition and morphological parameters were consistent around the area even after the dredging. This highlights the importance of planned and scientific dredging [3].

3.1.3. Passur River

To overcome the shortfalls, observe the performance and evaluate the targets, the concerned engineers of Mongla Port Authority worked with the consultant for the monitoring the performance of the dredging including hydrological and morphological impacts of dredging at the outer bar area in the Passur Channel. Due to the nearby location of the Sundarbans, the prime objective for the monitoring team was to minimize and prevent all possible negative impacts on the environment and morphology. Considering the scale and geographical conditions of the project, environmental perspectives were well considered. Most of the Environmental Management Plan (EMP) were implemented accordingly by the contractors. It was found that the baseline condition did not deteriorate significantly due to dredging. Due to the proper management of environmental perspectives, there was no significant environmental impact. All the impacts were reversible and expected to be restored to the raw healthy condition within a few days of finishing all the civil and mechanical interventions in and around the project sites. Therefore, no significant measure was recommended to tackle any of the environmental impacts. Hence, proper implementation of scientific dredging techniques worked behind the scenes for achieving such unprecedented success [4].

The results presented in Table 1 below shows that a few parameters were higher than the standard of drinking water. Dissolved Oxygen (DO) concentrations were good for the aquatic lives . But, the Chemical Oxygen Demand (COD) values showed higher concentrations which ranges from 103 mg/l to 184 mg/l during dredging and 155 mg/l to 208 mg/l after dredging. This presented low oxygen conditions which could be problematic for the aquatic environment. Besides, the other parameters were found to be within the standard values. This implies that no significant measure should be taken further to mitigate the effects on water quality. All these were possible because of using scientific and planned dredging techniques [4].

TABLE 1: Water Quality Monitoring Results during and after Dredging [4]

Water quality monitoring results during dredging

SL	Water Quality Parameters	Unit	Dredging Site (section 2)	Disposal Site: Dular Char	Dredging Site (section 1)	Disposal Site: Deep Sea	Standard
1	pH	-	7.56	7.5	7.6	6.9	6.5 – 8.5
2	Dissolved Oxygen(DO)	mg/L	6.02	6.77	6.1	6.7	≥ 6
3	Chemical OxygenDemand (COD)	mg/L	164	180	184	103	≤ 4
4	Total DissolvedSolids (TDS)	Mg/L	9550	9930	10255	13540	≤ 1000
5	Total SuspendedSolids (TSS)	Mg/L	5	12	7	9	≤ 10
6	Turbidity	NTU	115	109	98	147	≤ 10
7	Salinity	ppt	11.2	12.45	9.8	12.2	-
	Water quality monitoring results after dredging						
1	pH	-	7.79	7.40	7.1	6.9	6.5 – 8.5
2	Dissolved Oxygen(DO)	mg/L	6.24	6.18	6.5	6.8	≥ 6
3	Chemical OxygenDemand (COD)	mg/L	208	192	175	155	≤ 4
4	Total DissolvedSolids (TDS)	Mg/L	9760	10930	9300	9450	≤ 1000
5	Total SuspendedSolids (TSS)	Mg/L	4	9	5	7	≤ 10
6	Turbidity	NTU	13.8	30.2	35	125	≤ 10
7	Salinity	ppt	10	10.96	10.5	11	-

4. Methodology

This paper is an individual desk study. The research work provides a crystal clear idea about the significance of planned and scientific dredging. The paper also portrays the challenges that can put forward a difference in the big picture. This is a theoretical paper and a sound combination of existing thoughts and new ideas. Research conducted by other experts on different waterbeds helped the authors to look for the key points about the environmental impacts of dredging on ecosystem, biodiversity and social life in Bangladesh. The data collection included secondary sources; such as individual reports, newspaper articles, graphs, pictures and some other publicly available online and offline data. The authenticity of all the sources were examined before using and every point is elaborated with logical facts. This article is based on sources that the researchers consider reliable and the findings are referenced through citations.

5. Discussion

5.1. Primary Ecological Consequences of Dredging Activities in Bangladesh

Dredging activities in Bangladesh have immense ecological effects that extend even after the immediate dredging procedures. The dredged materials not only pose environmental concerns due to their heavy metal content and contamination but also trigger additional adverse ecological consequences upon disposal. Such as- turbidity, sedimentation and deposition of contaminants. The massive destruction of aquatic ecosystems like that of the Jamuna river ecosystems points out the splendid ecological impacts of dredging activities in Bangladesh. This destruction can lead to changes in water circulation patterns that enables saltwater intrusion into the estuaries and consequently affects the freshwater marine life in the affected areas. In addition to it, the release of carcinogenic substances like dioxins, PCBs and mercury into the water during dredging can result in massive environmental degradation causing adverse effects on the ecosystem in Bangladesh. The unsustainable nature of dredging in Bangladesh with the need for frequent repetition due to silting up of rivers and the eventual return to pre-dredged states underscores the long-term ecological damage inflicted by these practices. Environmentalists are increasingly recognizing that artificially deepening rivers through dredging may not only be ineffective but also counter-productive, highlighting the urgency for more sustainable and environmentally-friendly approaches to manage the waterways in Bangladesh [5] [6].

5.2. Effect of Dredging on the Biodiversity of Aquatic Ecosystems in Bangladesh

Dredging has far-reaching impacts on the biodiversity. The loss of natural habitats resulting from dredging can interrupt the balance for shallow-water fish seeking protection from river currents. It is because the newly dredged areas become unsuitable for their refuge needs. The creation of deeper habitats through dredging can consequently provide a conducive environment for non-native species to thrive and hence become more invasive. It poses a greater threat to the native biodiversity of Bangladesh's aquatic ecosystems. The turbidity caused by dredging activities can have detrimental side effects on the aquatic organisms that may lead to their decreased disease resistance, suffocation and even death as a result of poor water quality. The disturbance of sediments during dredging reduces visibility and increase water turbidity that further hinders the ecosystem's function and affects the growth of fish and other organisms due to a reduced food supply in turbid conditions. The overall poor water quality resulted from dredging has a severe impact on the marine life that ultimately affects the biodiversity of aquatic ecosystems in Bangladesh. Also, the suspension of silt and pollutants in the water during dredging activities in ports can create turbidity which further accelerates the negative impacts on aquatic ecosystems. All these points highlight the need for sustainable and scientific dredging practices to mitigate these adverse effects [5][6][7].

5.3. Social Implications Associated with Dredging Projects in Bangladesh

Dredging projects in Bangladesh have visible social implications that are resulted due to the immediate environmental impacts. The people in Bangladesh have come to experience annual flooding events as a result of the extensive dredging activities conducted in the rivers. It leads to a cycle of devastation of property and loss of life each year. While floods in Bangladesh can have multidimensional effects, the loss of life and property triggered by flooding cannot be overlooked. The dumping of dredged materials in an unorganized manner further accelerates ecological devastation in the region raising concerns about sustainability and the visible effects of human activities on the environment. Pollutants such as heavy metals and chemicals can accumulate in the environment raising risks to aquatic life and potentially contaminating water sources used for drinking and irrigation. The inadequate dredging practices result in the suspended silt that harms sensitive marine life and freshwater fish. It impacts the natural habitats and affects the overall ecological balance of the rivers and the people who live by those. This ecological imbalance threatens the aquatic species. It also compromises with the ecosystem services that the rivers provide, such as water purification and flood regulation, with far-reaching consequences for both human communities and the environment. The silt accumulation due to insufficient dredging decreases the fertility of agricultural lands and thus threatens the food security. It also disrupts the functions of waterways, irrigation canals and the livelihood of filter feeders in rivers. Consequently, it highlights the broader social implications of neglecting proper dredging practices. Neglecting proper dredging practices in one hand damages the agricultural productivity and economic development and on another hand jeopardizes ecosystems and community well-being. Changes in coastline structure due to sediment accumulation threaten coastal communities with increased erosion and flooding risks. These interconnected consequences highlight the importance of implementing effective dredging practices that prioritize environmental sustainability and safeguard the well-being of communities dependent on these vital aquatic resources. Ultimately, the unplanned or poorly executed dredging activities in Bangladesh are not only causing destruction to aquatic life but also contributing to the shrinking of rivers. It emphasizes the urgent need for more strategic and sustainable dredging practices in the region to minimize these social repercussions [5].

6. Recommendations:

To minimize the hazards resulted due to dredging operations, some recommendations are suggested below:

a) Scientific dredging techniques should be implemented in order to order to prevent environment pollutions.

b) Inadequate dredging practices lead to suspended silt that harms sensitive marine and upset the ecological balance of rivers. Proper planning and funding must be ensured beforehand to counter such situation.

c) Strict rules are to be implemented to stop illegal dredging of soil and sand materials.

d) Safety of the crew on board the dredger should be ensured before starting dredging operations.

e) Noise generated by dredging operations can lead to mental health hazards. So, it should not be conducted near a populated area.

f) Toxic sediments collected by dredging should not be dumped in freshwater.

g) Water quality, air quality and other environmental parameters should be monitored before and after conducting dredging activities. If any degradation of the environment is observed, such activities must be stopped immediately.

7. Conclusion:

While dredging is essential for Bangladesh’s economy and infrastructure, it is necessary to balance it with the environmental conservation and social welfare. This requires a multidimensional approach that involves careful planning, continuous monitoring and community engagement in order to ensure the sustainability of the water resources and the well-being of the communities that depend on them. Different studies already proved that planned and scientific dredging techniques have no or minimum negative effects on the environment. Hence it is possible to ensure the best possible outcomes from dredging activities in Bangladesh by minimizing its negative effects and by maximizing its overall productivity.

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Notes for the Contributors

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