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OPTIMIZATION OF THE PRELIMINARY DESIGN PARAMETERS AND COST EVALUATION OF CONTAINER VESSEL FOR THE INLAND WATERWAYS OF BANGLADESH.

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ABSTRACT

Demand of Containership for the inland waterways system in Bangladesh augmented on a large scale which forced to construct new containerships. The selection of the best design parameters and perform the necessary economic evaluations to ensure that the ship will make profit, is a great task for a Naval Architect. This paper represented an integrated methodology for the preliminary optimum design parameters considering the existing constraints provided by the Bangladesh Inland Water Transport Authority. The work is tackled from the ship owner's point of view. The required freight rate is chosen as the objective function because the most important thing that concerns the ship owner is whether the ship will make a profit or not, and if so, how much profit it can make. It is very important for the users to formulate carefully the optimization problems so that it gives a stable and reasonable solution.

Keywords: *containership, inland waterways, optimization, required freight rate, Bangladesh.*

NOMENCLATURE

R_{Total}	*Total resistance of a ship*
R_F	*Frictional Resistance*
R_{APP}	*Resistance of appendages*
R_W	*Wave-making and wave breaking resistance*
R_B	*Additional pressure resistance of bulbous bow nears the water surface*
R_{TR}	*Additional pressure resistance of immersed transom stern*
R_A	*Model-ship correlation resistance*
L	*Length on the waterline*
B	*Molded Breadth on the waterline*
T	*Draft of hull*
C_p	*Prismatic coefficient*
TEU_b	*Container number below deck*
TEU_d	*Container number above deck*
S_b	*Storage factors for containers below deck*
S_d	*Storage factors for containers above deck*
L_b	*Container number below deck along the length direction*
L_d	*Container number above deck along the length direction*
D_b	*Container number below deck along the depth direction*
TN_d	*Tier number for containers above deck*
W_h	*Hull steel weight*
W_{oh}	*Hull and outfit weight*
W_m	*Machinery weight*
Lut	*Time for loading and unloading containers per round Trip*
Pwt	*Port waiting time per round trip*
St	*Time spent at Sea*

1. INTRODUCTION

Bangladesh is a maritime nation with 166,000 sq.km area of sea, abundant with living and no living resources. Bangladesh also has a considerable domestic merchant shipping fleet for the transportation of passengers, food grains, machineries and oil products etc. Shipbuilding industries are essential to the requirement to support this fleet.

The basic ship design aims to determine major ship characteristics affecting cost and performance. Basic design includes the selection of ship dimensions, hull form, and power, preliminary arrangement of hull, machinery arrangement, and major structure. During the preliminary Ship Design phase, important decisions with significant impact on the vessel's performance have to be made by the designer, usually based on very limited information [4]. In such cases, the design has to rely on his experience and engineering judgment, occasionally supported by the exploration of relevant data from past designs.

Optimization methodology, facilitating the fast exploration of a series of design alternatives would be of great assistance to designer, in search of the 'optimum' solution subject to specific owner's requirements [8]. Proper selections assure the attainment of the mission requirements such as good seakeeping performance, maneuverability, desired speed, endurance, cargo capacity, and deadweight. Furthermore, it includes checks and modifications of the achievement of required cargo handling capability, quarters, subdivision and stability standards, and freeboard and tonnage measurements, usually defined as constraints. The derivation of a feasible technical design will take the form of an 'iterative process of analysis and synthesis'; i.e. is a repetitive process whereby the design is resolved into simple elements and relevant calculations made, after which the elements are combined into the total ship design [2]. The overall flow path shown in Figure 1 can thus be established. The preliminary design process will normally take the form of a techno-economic appraisal, using a fundamental engineering economy approach.

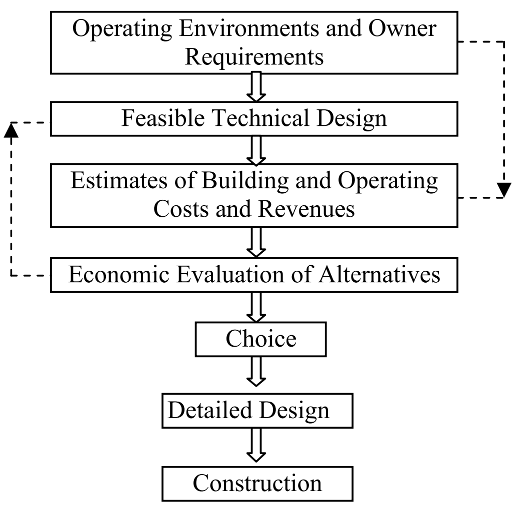

Figure1: Overall flow path.

2. GENERAL FORMULATION OF OPTIMIZATION PROBLEM

The target of optimization is the objective function or criterion of the optimization. It is subject to boundary conditions or constraints. Constraints may be formulated as equations or inequalities. All technical and economical relationships to be considered in the optimization model must be known and expressed as functions. The optimization problem is formally stated as follows [9]:

Minimize or maximize:

F(X) Objective Function … (1)

Subject to:

$K_j(X) \le 0$ j = 1, NCON Inequality Constraints

$X_i^L \le Xi \le X_i^U$ i = 1,NDV Side Constraints

Where X is the vector of design variables, NCON is the number of constraints, NDV is the number of design variables, X_i^L and X_i^U are the lower and upper bounds on the design variables. To solve and optimization problem, it is usually started with an initial design point, X^0. Then, the next design point is determined by:

$$X^{i+1} = X^i + \alpha.S^i \quad \dots (2)$$

Where I is the iteration number, α is the step length and S is the searching direction.

3. PERFORMANCE EVALUATION MODULE

The objective for the performance evaluation module is to calculate the technical and economical performance of the container ship for inland waterways of Bangladesh. Holtrop and Mennen's method is used for the resistance estimation. Container number calculated for a ship was also calculated. Some empirical formulae are used for weight and cost calculation.

3.1 Resistance Calculation

Holtrop and Mennen's method [5] is used to predict the resistance of the ship. The total resistance of a ship is divided into components as follows:

$$R_{Total} = R_F\,(1+K_1) + R_{APP} + R_W + R_B + R_{TR} + R_A \quad \dots (3)$$

As the containership is for the inland route of Bangladesh from Dhaka to Chittagong, bulbous bow was not provided to the ship. Here the frictional resistance, wave-making and wave breaking resistance and model-ship correlation resistance was calculated. Other components of total resistance such as appendage resistance (R_{APP}), resistance due to bulbous bow (R_B), transom resistance (R_{TR}) is ignored in the preliminary design calculation since they are very small percentage of total value. The ship is within the range of the condition for using Holtrop and Mennen's formulae. Condition is as follows [7]:

$0.55 < C_p < 0.85$
$3.9 < L/B < 15$
$2.1 < B/T < 4.0$

Holtrop's formulation is based on a statistical analysis of resistance data. All the component of the resistance was calculated for fixed speed of the vessel 11 knots. Effective Power (EHP) and Shaft Power (SHP) are also determined using empirical formulas.

3.2 Container Number Calculation

Container ships may be classified as capacity or space determined designs and their size are generally defined by their container capacity [2] – e.g. 1500, 3000, 6000 or 10000 TEU. (Container sizes

20′×8′×8.5′ height or 40′×8′ ×8.5′). TEU = Twenty foot Equivalent Unit (e.g. 40′ container = 2 TEU's). The number of Container carried by a vessel was calculated by the following expression [9]:

$$TEU = TEU_b + TEU_d \quad \dots \quad (5)$$

$$TEU_b = S_b \times L_b \times B_b \times D_b \quad \dots \quad (6)$$

$$TEU_d = S_d \times L_d \times B_d \times TN_d \quad \dots \quad (7)$$

Where TEU is the total number of containers (Twenty-foot Equivalent Unit). The actual number of Container that could be carried by the ship is the integer number.

3.3 Weight Estimation

Weight estimation can be done based on empirical regressions for structure, machinery, outfit and deadweight items other than cargo. The Naval Architect will always attempt to make the lightweight as low as possible without endangering the safety and strength of the new vessel [3]. The total weight of the ship is divided into components as follows:

$$W_{total} = W_{con} + W_{light} + W_{fuel} + W_{misc} \quad \dots \quad (8)$$

In this work, each TEU is considered as 14 TONNE. The lightship weight is further divided into sub-components as follows:

$$W_{light} = W_h + W_{oh} + W_m \quad \dots \quad (9)$$

Hull structure includes the main hull structure, superstructure, deck houses and all internal divisional bulkheads over one eight inch thick. Outfit constitutes hull insulation, joiner bulkheads, hawse pipes, deck fittings, cargo booms, hatch covers, anchors, rudder and stock and gallery equipment. The propulsion machinery weight is determined by the shaft horsepower of the main engine. Fuel weight is determined by the shaft horse power SHP, the service range, the speed of the ship, and specific fuel consumption of the engine with an additional ten-percent allowance.

3.4 Round Trip Time

The distance between the target ports (Dhaka – Chittagong) is about 307 Km (166 n. miles). Figure 2 shows the route between Dhaka and Chittagong with blue line on the map. On the route between Dhaka and Chittagong, there is the coastal channel across sandbars from Sandwip to South Hatia, where the shallowest part in the channel is deeper than 4.7m. About 2.0m of wave height is estimated at the coastal area but during cyclones, 1.5m to 4.4m of wave height were observed. The Navigational waterways between Dhaka and Chittagong or Mongla and the depth of waterways are to be controlled and guaranteed for vessel navigation by proper dredging throughout the year so that the vessel of 3.4m draft can operate all the seasons. Loading unloading time, Port waiting time and Sea time was calculated to estimate the number of trips that can be made by a ship throughout the year considering 15 off-hire days. It can be formulated as follows:

$$Rtt = Lut + Pwt + St \quad \dots \quad (10)$$

Therefore the number of trips per year is:

$$NT = \frac{Ot}{Rtt} \quad \dots \quad (11)$$

Where, Ot = on-hire time per year in days. In this work it is defined as 350 days.

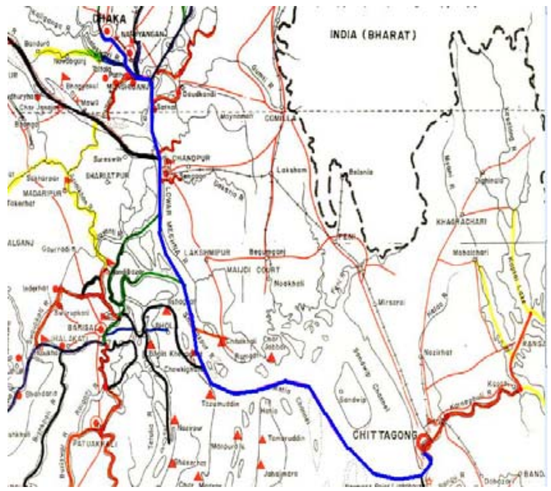

Figure 2: Map of Dhaka- Chittagong Route (Blue line)

3.5 Cost Estimation

3.5.1 Building Cost

The building cost comprises the cost for shipbuilding, including machinery, steel hull, hull engineering and outfit. The general idea for building cost is to calculate man hours required based on the weights of the related components and use the man-hour estimate to determine the labor cost [9]. The estimation of labor man-hours necessary for ship production, as a part of shipbuilding cost, has usually evolved at two stages of detail. The early stage provides only a preliminary estimate before any details of ship design and production processes are considered. Such preliminary estimates is made usually using empirical equations based on the ship weight, size and other general design parameters. A more detailed man-hours estimate starts after signing the contract, as the information of the project increases parallel with detail ship design, so as to make suitable planning and scheduling for shipbuilding process [1]. The material cost is calculated as a function of the weight. All the cost is taken from the market present value and in terms of local currency BD Taka.

3.5.2 Operating Cost

Operating Cost is the most important part after building the ship. Wages for the crews, stores and supplies, Insurance, Maintenance and Repair cost, Port expenses, Annual Fuel cost results the Annual operating cost [9]. In this case, Interest rate is defined as 15% and the ship life is defined as 30 year. Fuel cost is related to the SFC and the number of Trips that a ship can make.

3.5.3 Required Freight Rate

The supply of sea transport is influenced by freight rates. This is the ultimate regulator which the market uses to motivate decision-makers to adjust capacity in the short term, and to find ways of reducing their costs in the long-term. Required Freight rate is the amount the owner charges the customer to break-even. A more precise definition can be provided saying "The required freight rate for a given rate of utilization produces net profits which exactly cover the operating costs inclusive of calculated interest on the invested capital; i.e. profit and rate of return are nil." [9] In this work the required freight rate, expressed in TAKA per TEU per Trip. Therefore the required freight rate, RFR, is given by

$$RFR = \frac{Anual\ Average\ Cost}{Number\ of\ Trips\ X\ Total\ TEU} \quad \dots (12)$$

4. OPTIMIZATION PROCEDURE

Completing the general formulation for the optimization, each specific optimization problem was linked between each other in the Microsoft Excel, and the SOLVER add-in of Excel has been used to find out the optimum result. The formulation of the optimization problem includes three parts: selection of the design variables, formulation of the objective function and formulation of the constraints.

4.1 Objective function

The goal of this work is to develop a tool to help the designer find the best suitable ship design parameter which will make profit for its owner. The objective is to minimize the required freight rate with a fixed range between two ports (Dhaka- Chittagong). The objective function of this work is formulated as follows:

Objective function:

$$\textbf{Minimize}\ F(X) = \frac{RFR}{RFR0} \quad \dots (13)$$

where:

RFR_0: Required freight rate at the initial design point

4.2 Constraints

For the inland waterways for Bangladesh, the length, Breadth, and Depth are very much limited. The length to be required first is for container hold which is somewhat automatically decided by the number of container module. The Length of the ship was given 71m< L < 75m. The inadequate ship's proportion of length/breadth will raise an increase of resistance for propulsion which means an increase of horse power of main engine to keep the specified speed The Breadth of the ship should be within 12.5m < B <13.5m and the C_b is to be 0.70< C_b <.78. There was also a draft limit of 3.4 m and the speed of the vessel is fixed to 11 knots, although the program can be used for different draft and speed condition.

4.3 Design variable

There are several principles for choosing the design variables in an optimization problem. First, a design variable should have direct influence on the objective function and constraints. Second, the number of design variables should be kept as small as possible. Third, the design variables should be kept as independent as possible [9]. In this work Length, Breadth and Block coefficient used as design variable.

5. RESULTS & DISCUSSIONS

The work is done in two ways separately. A computer program in C++ was developed to give the maximum number of combination within the range and export the result in Microsoft Excel. Then the sorting was done for maximum container number, minimum resistance etc. A list of best 21 vessel's dimension was obtained for the graphical presentation. The speed and draft of the vessel was fixed for the inland waterways system. Speed was 11 knots and draft was 3.4 meter. On the other hand, whole formulation was also putted into four Microsoft Excel sheets. Each sheet was inter-connected. In the last sheet named Optimization, objective function, Variable and Constraints were defined. With the help of the SOLVER (Excel Add-in) the optimization process performed. Quadratic approach is used to obtain initial estimates of the basic variables in each one-dimensional search. Quadratic uses quadratic extrapolation, which can improve the results on highly nonlinear problems. Table 1 shows the lower and upper boundary of design constraint used by program as well as the optimum result found by the SOLVER.

Table1: Optimization result with respond to Limit.

	RFR (Taka)	L (m)	B (m)	D (m)	C_b	TEU
Lower Bound	8502.05	71	12.5	6	0.70	96
Upper Bound	8733.48	75	13.5	6.25	0.78	116
Result	8496.84	71	12.5	6	0.74	98

Four graph was produced for easy visualization of the changes occurred. In those entire four graphs it can be seen that between the length 74 and 75 there are some trough and crest shape. Each graph also have corresponding Contour plot, which can be used for determining the values for the intermediate Length, Breadth, TEU, RFR, SHP and AAC.

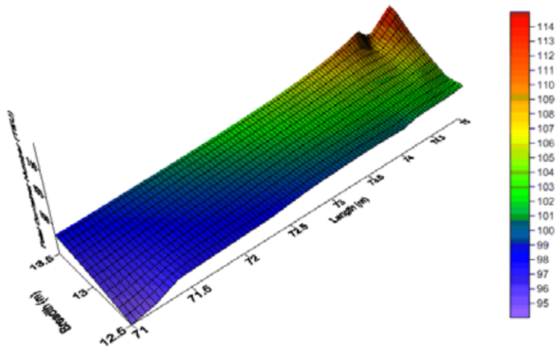

Figure 3: Total Container number (TEU) Vs Length, L (m) & Breadth, B (m).

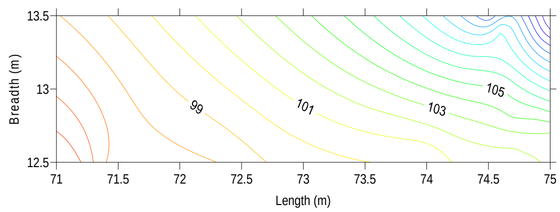

Figure 4: Total Container number (TEU) Vs Length (m) & Breadth (m). [Contour plot]

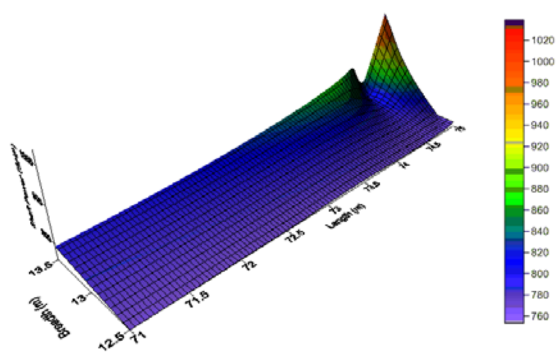

Figure 5: Shaft Power (SHP) Vs Length, L (m) & Breadth, B (m).

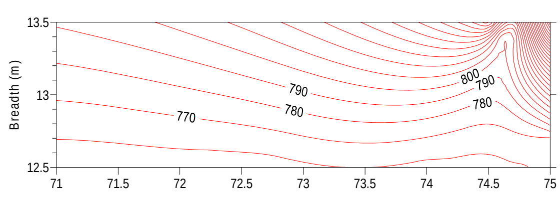

Figure 6: Shaft Power (HP) Vs Length (m) & Breadth (m). [Contour plot]

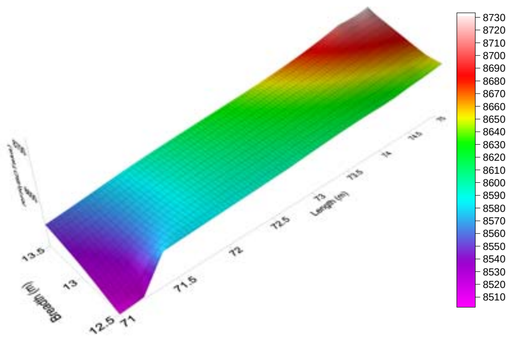

Figure 7: Required Freight Rate (BD Taka) Vs Length (m) & Breadth (m).

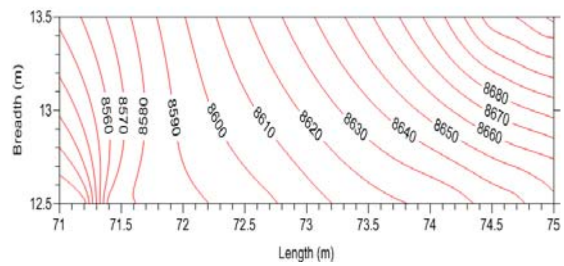

Figure 8: Contour Plot of Required Freight Rate (BD Taka) Vs Length (m) & Breadth (m).[Contour Plot]

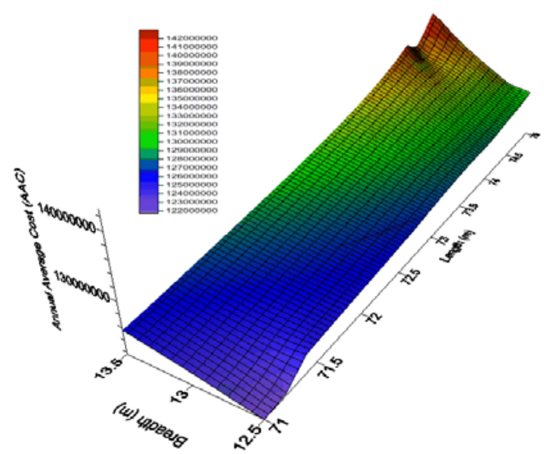

Figure 9: Annual Average Cost, AAC (BD Taka) Vs Length, L (m) & Breadth, B (m).

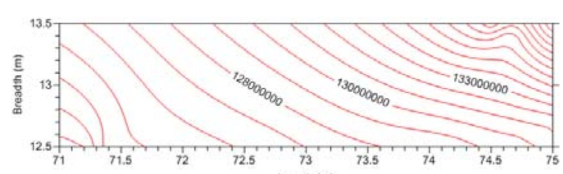

Figure 10: Annual Average Cost (BD Taka in million) Vs Length (m) & Breadth (m).[Contour plot]

Figure 3 and 4: establishes relationship among Total Container number, Length (m), and Breadth (m).It can be seen from the Figures that the number TEU increased with increasing length and breadth. Between the length 74 and 75 there was sudden trough and crest indicating the changes in the TEU. From the corresponding Contour plot, Total Container number can be found for a ship having Length between 71 to 75 meter and breadth between 12.5 and 13.5 meter. In Figure 5 and 6 shows a relationship among the Shaft Horsepower, Length and Breadth are established. A dramatic behavior in the Figure can be seen for the length between 74 and 75 meter. Maximum shaft horsepower is needed when the length and breadth is maximum. From the corresponding contour plot, values of probable SHP for the intermediate length and breadth can be estimated. In Figure 7 and 8 displays the most important relationship, RFR, Length and Breadth is established. RFR is calculated in terms of BD TAKA. From the Figure it can be observed the up and down of RFR for different values of length and breadth. With different length and breadth, optimum or desired RFR can be found from the corresponding contour plot. Final two Figure 9 and 10 shows the relationship among the Annual Average Cost (BD Taka), Length and Breadth of the ship. AAC increased for the maximum length and breadth but optimum point can be found from the contour plot of the corresponding relationships. Those Figures give the designer the preliminary idea of the important design parameters before going to the drawing table.

6. CONCLUSION

An integrated methodology for the basic preliminary design evaluation and optimization of Containership for inland waterways of Bangladesh has been presented. The reverine condition of Bangladesh has limited the option of thinking about large vessel. The main difficulty in most optimization problems does not lie in the mathematics or methods involved, i.e. whether a certain algorithm is more efficient or robust than others. The main difficulty lies in formulating the objective and all the constraints [6]. The optimization problem has been carefully formulated to give a stable solution. The design variables are chosen after careful inspection of every module. The constraints are based on the performance requirements. The objective function is normalized with respect to its initial value. For the cost evaluation process, empirical formulas along with the practical data were used. For the detailed cost evaluation, requires a separate work. From the result of the optimization we have conclusions as follows:

- We have only one global minimum point within our design space.
- The optimum container ship tends to be as big as possible.

ACKNOWLEDGMENTS

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