Brodogradnja/Shipbuilding Volume 66 Number 4, 2015

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ISSN 0007-215X
eISSN 1845-5859

OPTIMIZATION PROCEDURE FOR PRELIMINARY DESIGN STAGE OF CAIRO-DAMIETTA SELF-PROPELLED GRAIN BULK SHIPS

UDC 629.5.012:546.2
Professional paper

Summary

The global logistics center for the storage and handling of grain which will be constructed at Damietta port will extremely increase the annual movement of grain through Cairo-Damietta waterway. Therefore, the demand for inland grain bulk ships has increased significantly in the recent years.

This paper introduces a procedure to find out the fleet size and optimum characteristics of self-propelled grain bulk ships working between Cairo and Damietta through River Nile. The characteristics of the Cairo–Damietta waterway are investigated to define the constraints on dimensions and speed for such ship type. Also, mathematical model for the objective function was developed considering: powering, voyage, weight, stability and cost calculation. In this research, Specific cost (Sc), cost of transporting one ton of cargo a distance of one kilometre, is considered as the objective function for this optimization process.

This optimization problem is handled as a single objective nonlinear constrained optimization problem using a specially developed computer program. Solutions are generated by varying design variables systematically in certain steps. The best of these solutions is then taken as the estimated optimum. Finally, the problem is presented, the main constrains analyzed and the optimum solution shown.

Key words: *optimum ship design; inland grain bulk ship; Cairo-Damietta waterway;*

1. Introduction

Egypt is one of the largest importers of grain in the world. Where, Egypt and the surrounding region import about 50% of the size of the grain trade in the world. Hence the importance of the global logistics center for the storage and handling of grain, which its technical studies began in May, 2014. This center not only will cover the needs of the local market, but also will supply the surrounding regional markets by their needs. Therefore, the global logistics center for the storage and handling of grain will make Egypt the most important international hub for handling and storage of grain.

The Egyptian government was found that the Damietta port is best suited place for a number of key elements in the project. One of them it's excellent location on the Mediterranean Sea and near the northern entrance of Suez Canal. Also, Damietta port connects the Mediterranean Sea with the Egyptian inland waterways network.

On the other hand, 600 million tons of goods will need to be transported inside Egypt annually [1]. Therefore, the inland water transportation system has to be further developed if the country wants to cope with such a large rise in traffic of cargo. Nowadays, serious and prompt action is taken by the Ministry of Transport to increase river transport share in the transport of goods and planned to be up to 10% (60 million tons) of the transport volume in Egypt during the next ten years, instead of a 0.5% today. For this reason, River Transport Authority (RTA) implements a plan for the periodic maintenance and purges of the Egyptian inland waterways network, and thus contributing to facilitate transportation movement throughout the year.

The possible increase in the amount of goods, which will be transported through the River Nile, requires an increase in the size of the inland water transportation fleet. Therefore, the aim of the present work is to find out the optimum fleet size and dimensions of self-propelled grain bulk ships working between Cairo and Damietta through the River Nile.

2. Statement of the problem

The Egyptian government, in March 2015, said that a contract had been signed to construct the global logistics center for the storage and handling of grain at Damietta port. This project will extremely increase the annual movement of grain through Cairo-Damietta waterway. Therefore, a fleet of self-propelled grain bulk ships is to be designed and constructed. The fleet is to carry grain from Damietta port, where the global logistics center for the storage and handling of grain already exists, to Cairo which is considered as the most populated city in Egypt.

The fleet is to be designed according to the economic criterion discussed below which will deliver a total of 0.5 million tons of grain each year. Thus, a small saving in the cost of transportation one ton of cargo on this navigation route means a huge saving in money in the ship life. Therefore, it becomes mandatory that the ship's major characteristics have to be chosen very carefully. The design problem is to optimize the dimensions and speed of the vessel taking into account the existing navigation restrictions along Cairo-Damietta waterway.

3. Cairo-Damietta waterway

Cairo-Damietta waterway can be considered as the most important transportation path between Cairo and the outer exposed waterways to the open sea at Damietta Port. This waterway is classified as a first class waterway according to the classification of the General Egyptian River Transport Authority [2]. Characteristics of the first class waterways in Egypt are listed in Table1.

Table1 Characteristics of first class waterways in Egypt

Criterion	River Nile and its Branches
Min. bridge height	13 m
Min. water depth	2.5 m
Min. canal width	35 m
Max. ship draft	1.8 m

Cairo-Damietta waterway is about 260 Km long and mainly used for transportation of goods and raw materials by different ship types. The final 12 km of the navigation route to Damietta Port is via an artificial canal. This canal has a water depth of 4 m and width of 40 m at bottom level. Cairo-Damietta waterway has many restrictions that greatly influence navigation. The most important restrictions are the water depth, bridge height (air clearance) and the size of the locks. This waterway contains three locks (Delta barrages, Zifta and Faraskour), nine movable bridges and two fixed bridges. Faraskour lock is the smallest lock in Cairo-Damietta waterway where it has a length and width of 170 m and 17 m, respectively. Damietta high bridge is the lowest bridge in Cairo-Damietta waterway where its height is 8m above water surface at the highest tide level. Cairo-Damietta waterway is shown in Figure1.

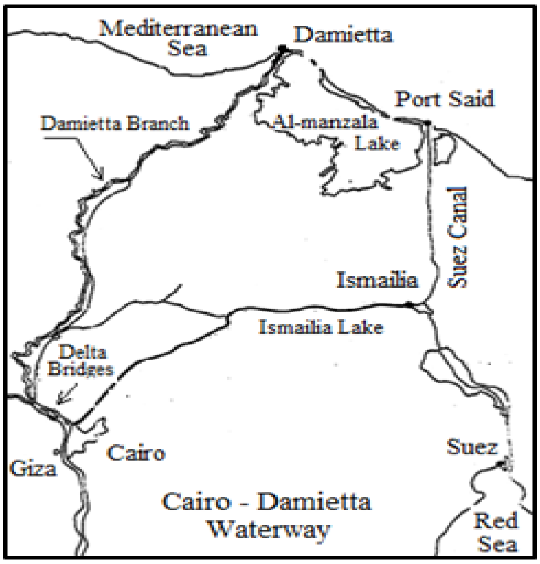

Fig. 1 Cairo-Damietta waterway

4. Optimization Problem

The problem under consideration is handled as a single objective nonlinear constrained optimization problem. This optimization problem can be formulated as follows, [3];

$$Find \quad X = \begin{Bmatrix} x_1 \\ x_2 \\ . \\ . \\ x_m \end{Bmatrix} \tag{1}$$

which maximizes an objective function called F(X) subjected to the following constraints;

$$g_j(X) \leq 0, \quad j = 1, 2, ..., q \tag{2}$$

$$\ell_j(X) = 0, \quad j = 1, 2, ..., p \tag{3}$$

where, “**m**” is the number of design variables. Also, “**q**” and “**p**” are the number of inequality and the equality constraints, respectively.

4.1 Objective function

The broad approach to choosing the best ship is quite easy to understand. Simply, it is to optimize a cost function which has been appropriately chosen. Specific cost (Sc), cost of transporting one ton of cargo a distance of one kilometre, is considered as the objective function for this optimization process. Thus, this optimization procedure leads to a minimum cost of shipping each ton of cargo each year. For each ship, specific cost can be calculated as follows [4]:

$$Sc = \frac{Average\ \ Annual\ \ Cost\ (AAC)}{Annual\ \ Transported\ \ Cargo * Route\ \ Distance} \tag{4}$$

$$AAC = \left(P - \frac{S_V}{(1-i)^N} + C_{tao} \right) . CR \tag{5}$$

Specific cost (Sc) can be obtained by a series of calculations. In order to do that it is most important that all cost considerations be given as functions of the physical variables [5]. If this can be accomplished prior to any decisions regarding the physical characteristics of the ships, then it will be possible to evaluate the objective function for any values of those variables.

4.2 Design variables

The problem under consideration involves eight design variables. These variables are shown in Table (2).

Table 2 List of design variables

No.	Design Variables	Explanation
1	N_S (ship)	Fleet size
2	Loa (m)	Length overall
3	B (m)	Molded breadth
4	Bst (m)	Width of side tank
5	T (m)	Design draft
6	D (m)	Molded depth
7	Hdb (m)	Height of double bottom
8	V_S (km/h)	Ship speed

4.3 Design constraints

The constraints are functional relationship between the design variables. These constraints define the feasible region from which the optimum solution has to be found.

4.3.1 Geometry constraints

Relationships between principal dimensions of self-propelled River Nile ships are investigated to clarify the acceptable limits on the dimensional ratios (Loa/B, Loa/D and B/T) for such ships. These constraints are formulated as follows [1]:

$$4.5 \leq \frac{Loa}{B} \leq 6.5 \tag{6}$$

$$14 \leq \frac{Loa}{D} \leq 26 \tag{7}$$

$$5 \leq \frac{B}{T} \leq 12 \tag{8}$$

4.3.2 Navigation constraints

Shallow water nature and the presence of locks and bridges along Cairo-Damietta waterway; represent several constraints on the speed and dimensions of Cairo-Damietta grain bulk ships. These constraints are formulated as follows;

1. The breadth of Cairo-Damietta grain bulk ships is dictated by the dimensions of Faraskour lock. Where, its dimensions are smaller than the dimensions of other locks. This constraint can be formulated as follows;

   $$B \leq 15.4\, m \tag{9}$$

   Maximum ship breadth is obtained after subtracting 1.6 m from the width of Faraskour lock (for each side, 0.3 m fender and 0.5 m clearance).

2. The draft of Cairo-Damietta grain bulk ships is often dictated by the shallow water nature of such navigation route. This constraint can be formulated as follows;

   $$T \leq 1.5\, m \tag{10}$$

3. The speed of Cairo-Damietta grain bulk ships is often dictated by the shallow water nature of such navigation route. The right choice of ship’s speed should be decided in the preliminary design stage based on the Froude depth number (Fnh) to avoid the critical region. In this study the Froude depth number is taken equal to 0.7, [1]. This constraint can be formulated as follows;

   $$\frac{V_S}{\sqrt{g\, h_w}} \leq 0.7 \tag{11}$$

4. The air draft of Cairo-Damietta grain bulk ships is often dictated by the existing bridges. Damietta high bridge is the lowest bridge in Cairo-Damietta waterway where its height is 8 m above water surface [2].

4.3.3 Constraint on block coefficient

Most inland vessels are characterized by large values of the hull block coefficients in order to achieve a larger displacement at low draught and decrease their building cost. Therefore, most inland vessels have a block coefficient (C_B) that varies from 0.8 to 0.9, [6]. This constraint can be formulated as follows;

$$0.8 \leq C_B \leq 0.9 \tag{12}$$

4.3.4 Weight Balance Constraint

This equality constraint is handled to enforce the balance between ship weight and displacement. This constraint can be formulated as follows;

$$\Delta = W_{light} + Dwt \tag{13}$$

4.3.5 Stability Constraint

The transverse metacentric height (GM_T) must be greater than 5% of ship breadth, [7]. This constraint can be formulated as follows;

$$GM_T \geq 0.05\,B \tag{14}$$

4.3.6 Freeboard Constraint

The freeboard (F_B) of the inland navigation ships must be greater than 0.5 meters, [8]. This constraint can be formulated as follows;

$$(D - T) \geq 0.5\,m \tag{15}$$

The required freeboard is compared, in the computer program, to the freeboard arrived at from volumetric requirements, and the larger of the two is used.

5. Model formulation

The subsequent sections provide the details of the modeling parameters and their mathematical formulation. The estimation methods that have been used to model the problem are also detailed.

5.1 Power evaluation

In this study, Equation (16) is used in the preliminary design stage to calculate the power (P_B) of a self-propelled Cairo-Damietta grain bulk ships, [1].

$$P_B = 0.02\,[Vs^3\ \Delta^{2/3}]^{0.841} \tag{16}$$

This equation (a form of Admirality Equation) has been developed using curve fitting with low regression coefficient [1]. It can be used also to calculate the preliminary power of self-propelled Cairo-Damietta grain bulk ships as it covers a lot of similar ships. Also, it is naturally that some points fall out of the average field covered by the curve fitted powers.

5.2 Trip calculation

The number of round trips per year (N_{trip}) mainly depends on the vessel operational days (VO_d), which is defined as the number of days per year in which the vessel is actively being used, either traveling between ports or loading or unloading at ports. For the purposes of this work, operational days (VO_d) are assumed to be 350, allowing 15 days per year for vessel maintenance and repair. The number of operational days divided by the round trip time (T_{trip}) determines the number of potential trips a vessel can make in a year.

$$N_{trip} = \frac{VO_d}{T_{trip}} \tag{17}$$

Round trip time (T_{trip}) is the taken time by a vessel to travel between two ports, including loading, unloading and any other eventuality. It can be calculated as follows:

$$T_{trip} = T_{nav} + T_{port} \tag{18}$$

Navigation time (T_{nav}) is the time the vessel spends traveling between ports, which depends on round trip distance and vessel speed. River Nile ships are prevented from sailing at night as a result of the currently improper navigational conditions on the waterway itself. Therefore, sailing time is taken equal to 12 hours per day. Navigation time can be calculated as follows:

$$T_{nav} = \frac{(1 + Na)\,Ru}{12\;Vs} \tag{19}$$

Port time is a function of vessel cargo capacity and the port cargo handling rate. Cargo handling operations can be continued for 24 hours per day in the River Nile terminals. In this paper, it is assumed that, loading time equals unloading time. Also, loading and unloading operation are carried out by terminal equipment. Port time is multiplied by two to reflect the loading and unloading activities in both origin and destination ports. Port time can be calculated as follows:

$$T_{port} = \frac{2\,(1 + Pa)\,Dwt}{24\,CHR} \tag{20}$$

The fuel and diesel consumption per trip (FC_{trip}) may be calculated according to the following equations;

$$FC_{trip} = FC_{nav} + DC_{port} + DC_{nav} \tag{21}$$

$$FC_{nav} = \frac{SFC\,.\,P_B\,.\,(12\,T_{nav})}{10^{-6}} \tag{22}$$

In the present study, the daily diesel oil consumption is taken equal to 2 tons for both port and navigation times.

5.3 Weight calculation

Ship weight (Δ) can be calculated according to the following equation:

$$\Delta = W_{light} + Dwt \tag{23}$$

Ship deadweight (Dwt) is a notation of the ship carrying capacity. Ship deadweight (Dwt) is taken as the weight of the cargo, fresh water, fuel and miscellaneous weights. Ship lightweight (W_{light}) , the weight of the complete ship, being ready for service but empty, is obtained by adding outfitting and machinery weights to the steel weight. In this study, 2% of light ship weight is taken as a margin [5]. The purpose of this margin is giving an allowance to ensure the attainment of the specified deadweight in case of underestimating the lightship weight, and also to compensate for possible departures from the initial weight design during construction.

Steel weight (W_{steel}) of Cairo-Damietta self-propelled grain bulk ships is calculated according to equation (24), [9]. In this paper, for transversely framed dry bulk vessels with draft equal to 1.5m, the coefficients (C_1 and C_2) are taken equal to 1.8E-5 and 2.37E-1, respectively [9].

$$W_{steel} = C_1 \left[L\,B\,T \right]^2 + C_2\, L\,B\,T \tag{24}$$

Outfitting weight (W_{out}) of Cairo-Damietta self-propelled grain bulk ships is calculated according to equation (25), [10].

$$W_{outfitl} = ko\ L\ B \tag{25}$$

where, ko is a coefficient based on ship types. ko is taken as 0.028 tons/m^2 for inland cargo ships, [11].The first step towards assessing the machinery weight ($W_{m/c}$) is the calculation of the required power to drive a ship. The second step involves taking a decision on the type of machinery best suited to the service conditions of the ship under consideration. In the absence of manufacturers' specifications, a value between (0.012 – 0.02 t/kw) can be used as approximate unit weight for medium speed diesel engines, [10]. In this study a value of 0.015 t/kw is used as approximate unit weights for diesel engines of Cairo-Damietta self-propelled grain bulk ships.

5.4 Stability calculation

The computer program alters the breadth of the proposed ship until the transverse metacentric height (GM_T) is at least 5% of ship breadth. The transverse metacentric height (GM_T) can be calculated according to the following formula:

$$GM_T = KB + BM_T - KG \tag{26}$$

The vertical center of buoyancy (KB), for inland ships, can be calculated according to the following formula, [12];

$$KB = 0.535\ T \tag{27}$$

The transverse metacentric radius (BM_T), can be calculated according to the following formula, [10];

$$BM_T = \frac{B^2}{24\,T\,C_B} \left[3\,C_{WL} - 1 \right] \tag{28}$$

The general assumption regarding the vertical center of gravity (KG) is that its position is 57% of the depth above keel.

5.5 Cost assessment

5.5.1 Ship capital cost

Ship capital Cost (P) is broken down into steel cost (C_{steel}), outfitting cost (C_{out}) and machinery cost (C_{mc}).

$$P = C_{steel} + C_{out} + C_{mc} \tag{29}$$

In this paper, 10% of ship capital cost (P) is taken as additional cost to cover the other costs (classification society, model testing, docking, external services, tugs ...etc). Also, it is assumed that, 50% of ship capital cost is equity capital and the rest is lend from a bank for 10 years annual equal payments at 10% interest.

Hull steel cost (C_{steel}) is calculated by multiplying the steel weight by a fixed value for manufacturing of one ton of steel. An average value of 8000 LE has been taken for the evaluation as a valid present figure.

Outfitting cost (C_{out}), being generally recognized as one of the most difficult and design-specific factors to calculate, is determined as a function of outfitting weight to the 2/3 power [5]. In this paper, based on a reference vessel, outfitting costs (C_{out}) can be calculated using the following formulae, [9];

$$C_{out} = 40000\, W_{out}^{\;2/3} \tag{30}$$

In this paper a value of 220 €/kW is used to determine the cost of the propulsion system (C_{mc}) for modern inland ship engines of 330 to 500 kW of rated power [9]. The main engine is the most expensive item in the ship's equipment and its share in the total costs of a ship can be up to 15%, [13]. Hence, minimizing the main engine power is of great importance [13]. Ship outfitting costs (C_{out}) and machinery costs (C_{mc}) are calculated in Euro. Therefore, in this paper, a factor of 8.5 is used to convert these costs to Egyptian pound.

5.5.2 Annual Operating Cost

Figure (2) shows the elements of ship annual operating cost. In the present work, the annual operating costs (C_{ao}) are allowed to escalate with a rate of 5% throughout the life span and projected again to the first year of ship's life using the present value techniques. Therefore, Equations (31) and (32) can be used to calculate ship annual operating cost at any year and present worth of life span operating expenses, respectively.

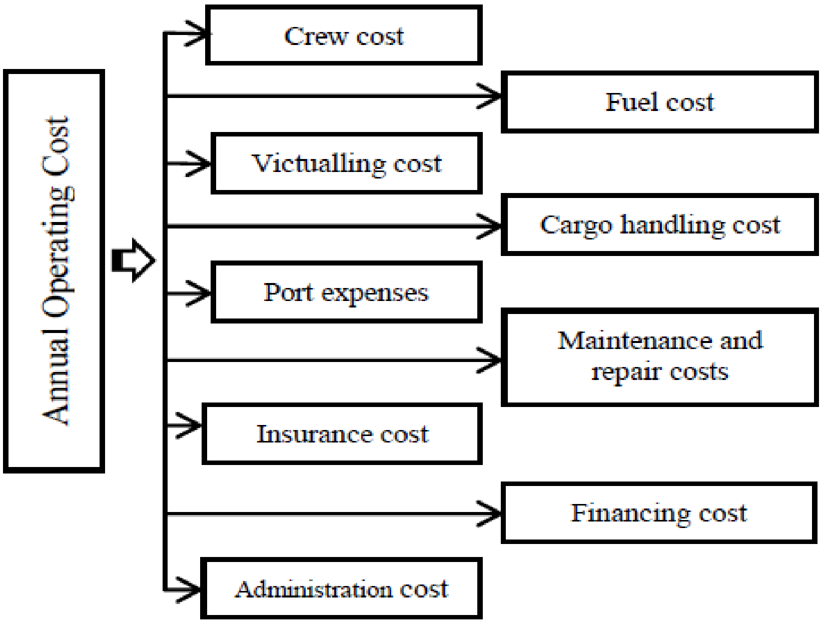

Fig.2 Annual operating cost

$$\left[C_{ao} \right]_n = C_{ao} \cdot \left[1.05^{\,n-1} \right] \tag{31}$$

$$C_{tao} = \sum_{n=1}^{N} \left(\frac{\left[C_{ao} \right]_n}{(1+i)^n} \right) \tag{32}$$

The crew cost (C_{wages}) may be calculated according to the following formula;

$$C_{wages} = 12\,A_{wage} \cdot N_{crew} \tag{33}$$

The annual fuel cost (C_{fuel}) may be calculated according to the equation;

$$C_{fuel} = FC_{trip} \cdot F_{price} \cdot N_{trip} \tag{34}$$

Victualling are usually bought locally at the ship's trading ports and the annual cost is calculated on a per person per day basis. Victualling cost (C_{Vict}) may be calculated according to the following equation;

$$C_{vict} = 350\,C_{day} \cdot N_{crew} \tag{35}$$

Ship carrying capacity are handled two times (loading and unloading) in each round trip. Cargo handling cost (C_{ch}) may be calculated according to the following equation;

$$C_{ch} = 2\,Dwt \cdot N_{trip} \cdot C_{hot} \tag{36}$$

The port expenses (C_{port}) may be calculated according to the following equation;

$$C_{port} = 2\,Dwt \cdot N_{trip} \cdot f_{port} \tag{37}$$

The maintenance and repair costs (C_{mar}) may be calculated according to the equations, [9];

$$C_{mar} = 5\,L\,B\,T + 0.009 \cdot \frac{T_{nav}}{T_{trip}} \cdot (12\,VO_d) \cdot P_B \tag{38}$$

This cost is calculated in Euro. Therefore, in this paper, a factor of 8.5 is used to convert this cost to Egyptian pound. Insurance costs (C_{insu}) may be calculated according to the following equation, [11];

$$C_{insu} = 0.11\,P \tag{39}$$

Administration cost (C_{admin}) is a contribution to the office expenses of a shipping company or the fees payable to a management company plus a considerable sum for communications and sundries. It can be taken equal to 10% of the annual operating costs, [11]. Financing cost (C_{fin}), during loan period, may be calculated according to the following equations [5];

$$R_b = p_b \cdot CR \tag{40}$$

$$CR = \frac{i\,(1+i)^{n_p}}{(1+i)^{n_p} - 1} \tag{41}$$

$$C_{fin} = R_b - \frac{P_b}{n_b} \tag{42}$$

where, Pb, Rb, n_b and CR are borrowed capital, bank annual payment, loan period and capital recovery factor, respectively.

6. Developed computer program

The present optimization problem is carried out by using a specially developed Visual Fortran computer program. This program is illustrated by the flow chart shown in Figure (3).

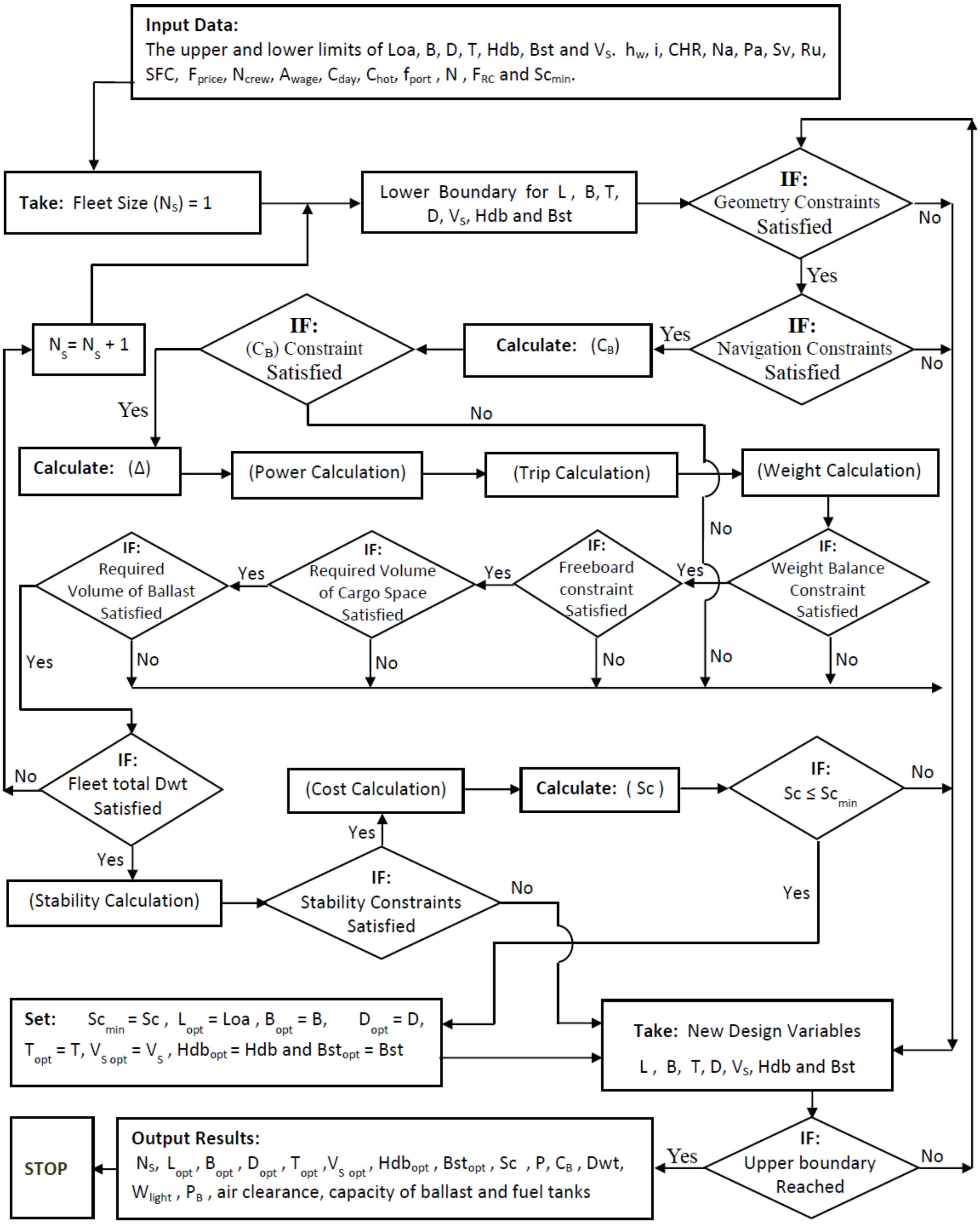

Fig.3 Flowchart for the developed computer program

In this program the design variables are varied in a sequential manner over a range of different step sizes. Thus, this program deals with a multi-dimensional problem whose size is a function of the number of variables, the step size and the specified range of each variable. The lower limit, upper limit and step size of the design variables are shown in Table 3.

Table 3 Lower limit, upper limit and step size of the design variables

No.	Design Variable	Lower Limit	Upper Limit	Step Size
1	N_S	1 ship	15 ship	1 ship
2	Loa	30.0 m	100.0 m	0.10 m
3	B	6.0 m	15.6 m	0.05 m
4	Bst	0.8 m	1.5 m	0.05 m
5	T	1.0 m	1.5 m	0.05 m
6	D	2.5 m	3.5 m	0.05 m
7	Hdb	0.8 m	1.0 m	0.05 m
8	V_S	10 km/h	18 km/h	0.2 km/h

In this paper, lower limits of double bottom height and width of side tanks are taken equal to 0.8 m as required by the Egyptian River Transport Authority (RTA). Also, double bottom height and width of side tanks are chosen to provide enough volume for the required ballast quantity (at least 60% of cargo weight). Table (4) contains the input data of the developed program while Table (5) contains the output results.

Table 4 Input Data – Developed Program

No.	Item		Value
1	Water depth	(h_w)	2.5 m
2	Round trip distance	(Ru)	520 km
3	Nile allowance	(Na)	0.10
4	Port allowance	(Pa)	0.20
5	Ship life	(N)	25 years
6	Scrap value	(Sv)	0.15
7	Interest rate	(i)	10%
8	Cargo handling rate	(CHR)	50 ton/h
9	Cargo handling cost	(C_{hot})	5 LE/ton
10	Port expenses	(f_{port})	1.0 LE/ton
11	Number of crew	(N_{crew})	8 crew
12	Average wage per person	(A_{wage})	2000 LE/month
13	Fuel price	(F_{price})	2000 LE/ton
14	Specific fuel consumption	(SFC)	150 gr/hp/h
15	Daily accommodating cost per person	(C_{day})	25 LE/day
16	Minimum specific cost	(Sc_{min})	0.35 LE/(ton.km)
17	Fleet required annual grain capacity	(F_{RC})	0.5 million tons/year

Table 5 Output results - developed program

No.	Items		Result
1	Objective Function (Sc)		0.285 LE/(ton.km)
2	Design variables	Fleet Size (N_S)	11 Ship
3		Length Over All (Loa)	67.8 m
4		Ship Breadth (B)	11.75 m
5		Ship Depth (D)	3.5 m
6		Ship Draft (T)	1.5 m
7		Width of Side Tank (Bst)	1.25 m
8		Double Bottom Height (Hdb)	1.0 m
9		Ship Speed (V_S)	12.4 km/h
10	Air Clearance		1.0 m
11	Block Coefficient (C_B)		0.889
12	Ship Capital Cost (P)		6,521,139 LE
13	Ship Deadweight (Dwt)		706.88 tons
14	Ship Lightweight (W_{light})		344 tons
15	Engine Brake Power (P_B)		554.77 hp
16	Capacity of Fuel Tanks		30 m^3
17	Capacity of Ballast Tanks		620 m^3

7. Conclusions

1. The global logistics center for the storage and handling of grain at Damietta port will extremely increase the annual movement of grain through Cairo-Damietta waterway and consequently, will Increase River transport share in Egypt during the next years, instead of a half per cent today.
2. The developed computer program represents a tailored and simple tool to find out the optimum fleet size and dimensions of self-propelled grain bulk ships working between Cairo and Damietta through the River Nile. This program may be simply modified to suit not only the other navigation routes but also the other River Nile ship types.
3. The output results of the developed program may be taken as a standard dimensions for any new self-propelled grain bulk ship works through Cairo-Damietta waterway. Also, according to the characteristics of Cairo-Aswan waterway, this fleet can be navigated from Damietta to Aswan.
4. Increasing the sailing time per day through the River Nile, will decrease the cost of cargo transportation and consequently, will highly encourage the transportation companies to shift their activities to the River Nile transportation mode.

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NOMENCLATURE

AAC Average annual cost, LE/year
A_{wage} Average wage per person, LE/month
B Ship breadth, m
Bst Width of side tank, m
BM_T Transverse metacentric radius, m
CHR Cargo handling rate, ton/h
CR Capital recovery factor, "__"
C_B Block coefficient, "__"
C_{admin} Administration cost, LE/year
C_{ao} Annual operating cost, LE/year
C_{ch} Cargo handling cost, LE/year
C_{day} Accommodating cost, LE/day/person
C_{fin} Financing cost, LE/year
C_{fuel} Fuel cost, LE/year
C_{hot} Cargo handling cost, LE/ton
C_{insu} Insurance cost, LE/year
C_{mar} Maintenance and repair costs, LE/year
C_{mc} Machinery cost, LE
C_{out} Outfitting cost, LE
C_{port} Port expenses, LE/year
C_{steel} Hull steel cost, LE
C_{vict} Victualling cost, LE/year
C_{tao} Present worth of life span operating expenses, LE
C_{WL} Water plan area coefficient, "__"

C_{wages}	crew cost, LE/year
D	Ship depth, m
DC_{nav}	Diesel oil consumption at sea, tons/trip
Dwt	Dead weight, tons
F_B	Freeboard, m
F_{RC}	Fleet required annual grain capacity, tons/year
F_{price}	Fuel price, LE/ton
FC_{nav}	Fuel consumption at sea, tons/trip
FC_{port}	Fuel consumption at port, tons/trip
FC_{trip}	Total fuel consumption, tons/trip
Fnh	Froude depth number, "__"
f_{port}	Port expenses, LE/ton
GM_T	Transverse metacentric height, m
Hdb	Double bottom height, m
h_w	Water depth, m
i	interest rate, "__"
K_B	Vertical center of buoyancy, m
K_G	Vertical center of gravity, m
LE	Egyptian pound, "__"
Loa	Length over all, m
N	Ship life, years
Na	Nile allowance, "__"
Ns	Fleet size, ship
N_{crew}	Number of crew, crew
N_{trip}	Number of round trips per year, trip/year
n_p	Loan period, years
P	Ship capital cost, LE
Pa	Port allowance, "__"
P_B	Brake power, hp
R_b	Bank annual payment, LE/year
Ru	Round trip distance, km
Sc	Specific cost, LE/(ton.km)
SFC	Specific fuel consumption, gr/hp/h
SHP	Shaft power, hp
Sv	Scrap value, LE
T	Ship draft, m
T_{nav}	Sea time, days/trip
T_{port}	Port time, days/trip
T_{trip}	Total trip time, days
VO_d	Operation time per year, days/year
V_S	Ship speed, km/h
W_{light}	Light ship weight, tons
$W_{m/c}$	Machinery weight, tons
W_{out}	Outfitting weight, tons
W_{steel}	Net steel weight, tons
Δ	Ship displacement, tons

Submitted: 15.08.2015.
Accepted: 13.12.2015.

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