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Techno-Economical Optimization for River Nile Container Ships

Professional paper

This work introduces a procedure for the preliminary design of a self-propelled container ship working between Cairo and Aswan through the River Nile. The characteristics of the navigation route from Cairo to Aswan are investigated to define the constraints on dimensions and speed of the River Nile container ships. Also, the dimensions of some existing inland ships are collected and investigated to set limits on the dimensional ratios of such ships. Two empirical formulae, for the determination of ship steel weight and power prediction in the preliminary design stage of conventional self propelled inland container ships, are proposed. This problem is handled as a single objective constrained optimization problem using a specially developed computer program (CACSO). As the required freight rate reflects the major goal of any commercial ship, it is considered as the objective function for this optimization process. A sensitivity study is carried out to indicate the relative dependence of the objective function on a variety of factors to which the objective function may be sensitive.

Keywords: *inland container ship, optimization, River Nile*

Tehničko-ekonomska optimizacija kontejnerskih brodova za rijeku Nil

Stručni rad

Ovaj rad prikazuje postupak preliminarnog osnivanja kontejnerskog broda s vlastitim pogonom za plovidbu rijekom Nil na relaciji Kairo – Asuan. Značajke plovidbene rute po rijeci Nil od Kaira do Asuana istražene su kako bi se definirala ograničenja značajki i brzina kontejnerskog broda. Također su prikupljeni podaci postojećih brodova unutarnje plovidbe radi postavljanja ograničenja omjera značajki ovih brodova. Predložene su dvije iskustvene formule za određivanje mase čelika i procjenu snage u preliminarnom osnivanju konvencionalnih brodova unutarnje plovidbe s vlastitim pogonom. Ovaj problem se rješava kao jedno-ciljna optimizacija s ograničenjima koristeći posebno razvijeni program (CACSO) za ovu svrhu. Kako zahtijevana vozarina predstavlja glavni cilj svakog ekonomski isplativog broda, uzeta je kao funkcija cilja u procesu optimizacije. Napravljena je studija senzitivnosti kako bi se odredila relativna ovisnost funkcije cilja o raznim čimbenicima na koje je ona osjetljiva.

Ključne riječi: *optimizacija, riječni kontejnerski brod, rijeka Nil*

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1 Introduction

Inland navigation is a water-born transport mode whose specific characteristics make it an interesting alternative to both, land-born truck and rail transport modes. Although, Egypt is characterized by a vast network of waterways, the water-born transport mode has a very low position relative to the other transport modes as a consequence of numerous economical and political reasons.

According to the ministry of transport, in less than a decade, 600 million tons of goods will need to be transported inside Egypt annually. 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.

The Egyptian government increased the investment in the field of inland water transportation to enable much higher utilization of the Egyptian waterways in the near future, and also to reduce the ever increasing congestion on Egyptian motorways.

The possible increase in the amount of goods, which will be transported through the River Nile, requires an increase in the volume of the inland water transportation fleet. The aim of the present work is to find out the optimum dimensions and speed of a new Container ship working between Cairo and Aswan through the River Nile.

2 Optimization problem

There are two principal ways to handle “multi-objective” problems, both leading to single objective optimization problems [1]:

1. One objective is selected and the other objectives are formulated as constraints.
2. A weighted sum, of all objectives, forms the optimization objective function.

The rather arbitrary choice of weight factors makes the optimization model obscure and the first option is mostly preferred [1]. Therefore, in this study, the problem under consideration is handled as a single objective constrained optimization problem according to the first option.

This optimization problem can be formulated as follows [2]:

$$\text{Find } X = \begin{Bmatrix} x_1 \\ x_2 \\ . \\ . \\ x_m \end{Bmatrix} \qquad (1)$$

which maximizes an objective function called $f(X)$ subjected to the following constraints:

$$\left.\begin{array}{l} g_j(X) \le 0,\ j = 1, 2, \ldots\ldots\ldots, q \\ \text{and} \\ \ell_j(X) = 0,\ j = q+1, q+2, \ldots.., p \end{array}\right\} \qquad (2)$$

where, $g_j(X)$ and $\ell_j(X)$ are the inequality and the equality constraints respectively.

2.1 Objective function

As the required freight rate (RFR) reflects the major goal of any commercial ship, it is decided upon as the objective function for this optimization process. In this work it is useful to define the minimum freight rate which must be charged to break even over the life of the ship. Practically, any freight rate above the required freight rate would lead to profits. Optimization is used to minimize the required freight rate (RFR) that is calculated as LE/TEU. The objective function for this optimization process can be formulated as follows:

$$RFR = \frac{AAC}{Transported\ Container\ Per\ Year} \qquad (3)$$

2.2 Design variables

The problem under consideration involves five design variables. These variables are listed in Table 1. Most of these variables are for the ship principal dimensions with the exception of ship speed. The speed of the ship is the cruising speed. It is assumed that this speed is the average speed of the ship during its journey.

Table 1 **List of design variables**
Tablica 1 **Popis projektnih varijabli**

Design Variable	Units	Explanation
Loa	Meters	Length overall
B	Meters	Molded breadth
T	Meters	Design draught
D	Meters	Molded depth
V_S	Km/h	Ship speed

2.3 Design constraints

The constraints are functional relationship between the design variables. These constraints define the space of acceptable solutions (feasible region) from which the best solution has to be found.

2.3.1 Navigation constraints

The presence of locks and bridges along the waterway and shallow water nature of the River Nile, represent several constraints on the dimensions of the Nile ship. These constraints are formulated as follows:

1. The width and length of the Nile ship are dictated by the dimensions of Assiut lock. Where, its dimensions are smaller than the dimensions of other locks, see Table 2. These constraints can be formulated as follows:

$$(Loa - 72.0) \le 0 \qquad (4)$$

$$(B - 14.4) \le 0 \qquad (5)$$

The maximum ship length is obtained after subtracting 8.0 m from the length of Assiut lock to open the gates. While,

Table 2 **Characteristics of the existing structures along the waterway from Aswan High Dam to Delta bridges** [4]
Tablica 2 **Značajke postojećih struktura duž plovnog puta od Asuanske visoke brane do mostova na delti Nila** [4]

No	Industrial Structure	Opening			Air Clearance (m)
		No.	Breadth (m)	Length (m)	
1	Aswan High Dam	-	-	-	-
2	Aswan new bridge	The River Nile Width			13
3	Edfu high bridge	3	50	-	13
4	Isna lock	1	17	116	-
5	Louxor bridge	1	90	-	13
6	Kena high bridge	3	50	-	13
7	Kena bridge (rail)	5	80	-	13
8	Nagaa Hamadi bridge	2	38	-	Movable
9	Nagaa Hamadi bridge	2	38	-	Movable
10	Nagaa Hamadi lock	1	17	140	-
11	Sohag bridge	3	40	-	13
12	Assiut bridge	3	45	-	13
13	Assiut lock	1	16	80	-
14	Al-Menia bridge	2	50		13
15	Bany- Swaif bridge	2	47	-	13
16	Al-Marazik bridge	1	85	-	13
17	Al-Monib bridge	2	150	-	13
18	Giza high Dam	1	110	-	11
19	Al-Gamaa bridge	1	110	-	12
20	Al-Galaa bridge	2	30	-	Movable
21	6th October bridge	1	55	-	10
22	15th May bridge	1	45	-	10
23	Embaba bridge (rail)	2	21	-	Movable
24	Rode El-Farag bridge	1	110	-	10
25	Delta bridges	1	16	116	-

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

2. The draught of the Nile ship is often dictated by the shallow water nature of the River Nile. This constraint can be formulated as follows:

$$(T - 1.5) \le 0 \tag{6}$$

3. The air draught is often dictated by the existing bridges. This constraint restricts the number of container layers onboard inland container ships.
   It can be seen from Table 2 that the smallest air clearance is 10.0 m. Therefore, the maximum allowable number of container layers is 4.0 layers. This constraint can be formulated as follows:

$$(N_{\text{layer}} - 4.0) \le 0 \tag{7}$$

Table 3 **Principal dimensions for 21 self-propelled inland ships**
Tablica 3 **Glavne značajke 21 broda unutrašnje plovidbe s vlastitim pogonom**

Ship No.	Loa (m)	B (m)	T (m)	D (m)
1	59.4	10.73	1.24	3.3
2	70.6	14.8	1.5	3.4
3	51	9.5	1.2	3.5
4	69	13.22	1.48	3.65
5	72	13	1.5	3.25
6	64.2	11.62	1.41	3.54
7	67.2	11.2	1.12	3.26
8	62	11.5	1.5	3.5
9	72	14	1.4	3.8
10	47.4	10	1.2	1.8
11	69.5	13.9	1.16	3.38
12	60.2	11.4	1.18	3.5
13	71.5	13.5	1.6	3.58
14	72	13.5	1.4	3.5
15	49.5	7.95	1.5	3.1
16	72	13.5	1.25	3.3
17	72	14	1.3	3.4
18	54.25	9.6	1	3
19	71.5	13	1.45	3.5
20	71.8	12.1	1.5	3.15
21	60.5	9.6	1.406	3.25

4. The speed of Nile ship is often dictated by the shallow water nature of the River Nile.

$$V_S \le 18.0 \text{ km/h}$$

The right choice of ship's speed should be decided in the very early design stage based on the Froude depth number (Fnh) to avoid the critical region.

In this work the Froude depth number is taken equal to 0.7 [3]. This constraint can be formulated as follows:

$$\left(\frac{V_S}{\sqrt{g * h_W}} - 0.7\right) \le 0 \tag{8}$$

2.3.2 Geometry constraints

The principal dimensions for 21 self-propelled inland ships has been collected in Table 3 and investigated to clarify the acceptable limits on the dimensional ratios (*Loa*/*D*, *Loa*/*B* and *B*/*T*) for such ships.

2.3.2.1 Constraint on (*Loa/D*) ratio

The value of (*Loa*/*D*) is significant in relation to the structural strength of the ship and in particular to the deflection of the hull girder under the bending moment imposed by waves and cargo distribution.

Figure 1 shows that the length to depth ratio of the River Nile ships varies between 14 and 26. This constraint can be formulated as follows:

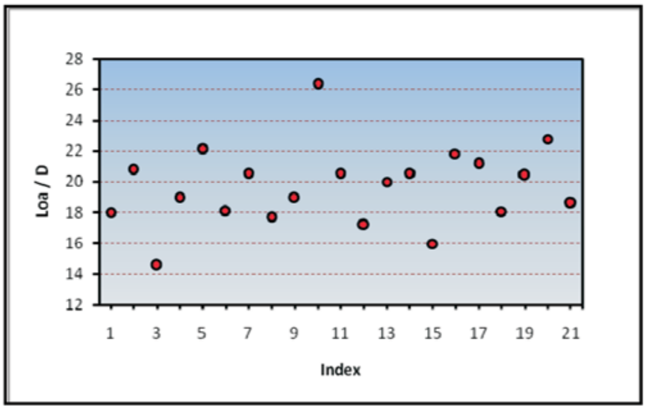


Figure 1 **Length to Depth Ratio for the River Nile Ships**
Slika 1 **Omjeri duljine i visine za riječne brodove na Nilu**

$$(Loa - 26 * D) \le 0 \tag{9}$$

$$(14 * D - Loa) \le 0 \tag{10}$$

2.3.2.2 Constraint on (*Loa/B*) ratio

Inland container vessels should have full hull form, due to draught restrictions, but *Loa*/*B* ratio, long or beamy vessel, has yet to be clarified. Longer vessels should be advantageous from the wave resistance point of view, while the beamy vessels would be better in stability and hull weight considerations. Figure 2 shows that the length to breadth ratio of the River Nile ships varies between 4.5 and 6.5. This constraint can be formulated as follows:

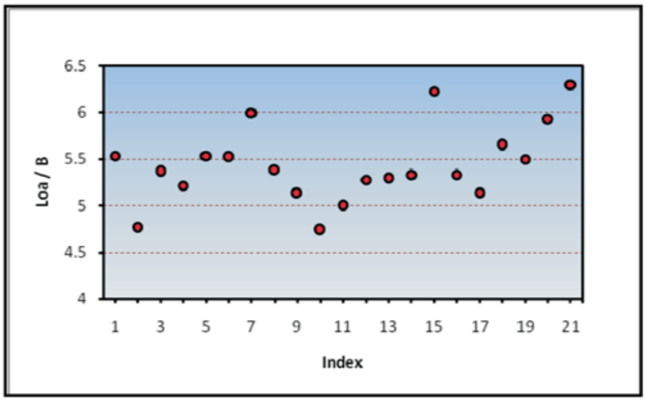


Figure 2 **Length to Breadth Ratio for the River Nile Ships**
Slika 2 **Omjeri duljine i širine za riječne brodove na Nilu**

$$(Loa - 6.5 * B) \leq 0 \tag{11}$$

$$(4.5 * B - Loa) \leq 0 \tag{12}$$

2.3.2.3 Constraint on (*B/T*) ratio

It may be noted that for a fixed displacement, increasing the (*B/T*) ratio will cause an increase in ship resistance and capital cost. Figure 3 shows that the breadth to draught ratio of inland navigation ships varies between 5 and 12. This constraint can be formulated as follows:

$$(B - 12 * T) \leq 0 \tag{13}$$

$$(5 * T - B) \leq 0 \tag{14}$$

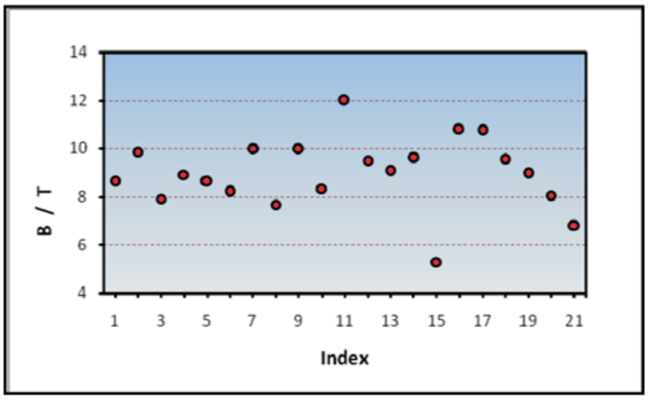


Figure 3 **Breadth to Draught Ratio for the River Nile Ships**
Slika 3 **Omjeri širine gaza za riječne brodove na Nilu**

2.3.2.4 Constraint on Block Coefficient (C_B)

Most inland vessels are characterized by great values of the hull block coefficients in order to achieve a larger displacement at low draught and decrease their building cost. Therefore, for most inland vessels a block coefficient varies from 0.8 to 0.9 [5]. This constraint can be formulated as follows:

$$(0.8 - C_{\mathrm{B}}) \leq 0 \tag{15}$$

$$(C_{\mathrm{B}} - 0.9) \leq 0 \tag{16}$$

2.3.3 Weight balance constraint

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

$$L * B * T * C_{\mathrm{B}} - W_{\mathrm{light}} - Dwt = 0 \tag{17}$$

2.3.3 Stability constraint (GM_T)

The transverse metacentric height (GM_T) of the inland container ship must be greater than 1.0 meters [6]. This constraint can be formulated as follows:

$$(1.0 - GM_{\mathrm{T}}) \leq 0 \tag{18}$$

2.3.4 Freeboard constraint

The freeboard of the inland container ships must be greater than 0.5 meters [6]. This constraint can be formulated as follows:

$$(0.5 - D + T) \leq 0 \tag{19}$$

2.3.5 Rolling constraints

This inequality constraint depends on the minimum required rolling period (T_{roll}) criterion. It is regarded as a constraint to keep the transverse metacentric height (GM_T) from getting too high. In this work the minimum rolling period is taken equal to 15 seconds [7]. The transverse rolling period can be calculated according to the following equation [1]:

$$T_{\mathrm{roll}} = \frac{2\pi * K}{\sqrt{g * GM_{\mathrm{T}}}} \tag{20}$$

The radius of gyration is taken equal to 0.385*B [8]. This constraint can be formulated as follows:

$$(15 - \frac{0.77 * B}{\sqrt{GM_{\mathrm{T}}}}) \leq 0 \tag{21}$$

3 Design modules

The first step in ship design is to use appropriate analytical and empirical relationships to obtain the geometry, weight and consequently the engine power. These relationships may be directly or indirectly proportional to the dimensions, vessel types, used materials, weight, etc.

3.1 Power module

In shallow water, vessel's resistance is very much different than in deep water and may play the most important role in inland vessel's design. There are some empirical methods developed for calculating the engine power in the early design stage of sea going ship [9]. These methods cannot be applied to inland ships.

$$P_{\mathrm{B}} = 0.02 * \left[V_S^3 \Delta^{2/3} \right]^{0.841} \tag{22}$$

In this work, equation (22) may be used in the early design stage to calculate the power of conventional self propelled inland units.

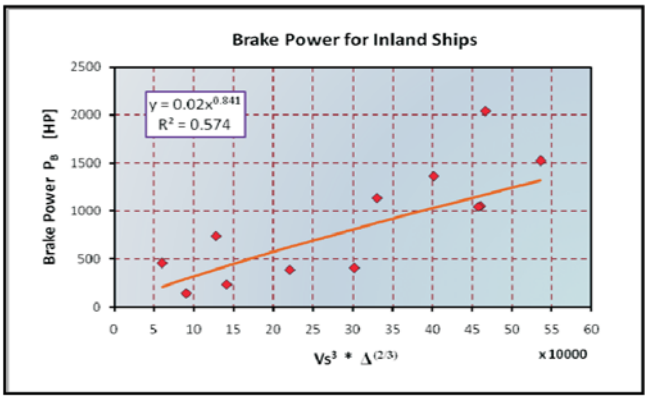


Figure 4 **Power of inland ships**
Slika 4 **Ugrađene snage riječnih brodova**

This equation has been developed by plotting the particulars of some existing inland units, as shown in Figure 4.

3.2 Trip module

The total trip time (TTd) is consisting of the time spent at sea and time spent at ports. The annual sea and port time may be calculated after calculating the annual number of trips (Tn) as follows:

$$Tn = \frac{350}{TTd} \tag{23}$$

$$TTd = STd + PTd \tag{24}$$

$$STd = \frac{(1+Ra)Ru}{12 * Vs} \tag{25}$$

$$PTd = \frac{2 * (1+Pa) * N_C}{24 * C.H.R} \tag{26}$$

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. However, containers handling operations can be continued for 24 hours per day in the River Nile terminals.

The fuel and diesel consumption per trip (FCT) may be calculated according to the following equations:

$$FCT = FCS + FCP + DCS \tag{27}$$

$$FCS = \frac{SFC * P_B * (STd * 12.0)}{10^6} \tag{28}$$

For self-loading and unloading ships, it is possible to take the daily diesel oil consumption at port and sea equal to 5 and 2 ton respectively [10]. For inland container ships, loading and unloading operations are carried out by the containers handling equipment of the river terminals. Therefore, in the present study, the daily diesel oil consumption is taken as follows:

$$FCP = 2.0 * PTd \tag{29}$$

$$DCS = 2.0 * STd \tag{30}$$

3.3 Weight module

3.3.1 Light ship weight

The lightship weight (W_{light}) may be calculated according to the following equation:

$$W_{light} = W_{steel} + W_{out} + W_{m/c} + \text{Margin} \tag{31}$$

3.3.1.1 Steel weight

Some empirical methods are available for calculating ship steel weight in the early design stage of sea going ship [1 and 9]. These methods cannot be applied to inland ships.

In the present work, ship steel weight is estimated using Equation (32). This equation has been specially developed on the basis of the steel weights of some existing inland ships and the computed steel weights obtained from construction drawings produced specially for this reason as shown in Figure 5.

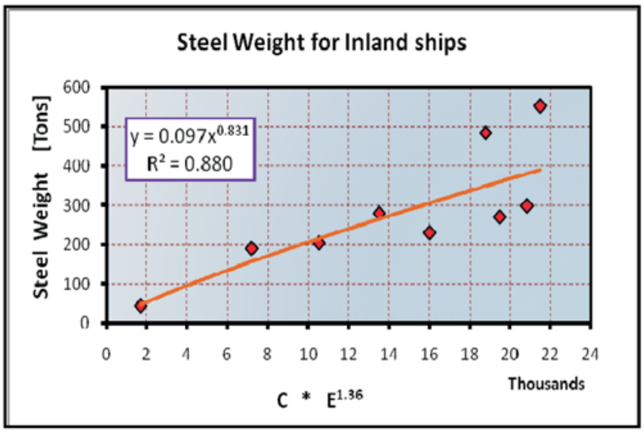


Figure 5 **Steel weight of inland ships**
Slika 5 **Masa čelika riječnih brodova**

$$W_{steel} = 0.097 * [C * E^{1.36}]^{0.831} \tag{32}$$

$$C = [\,1 + 0.05 * (C_B' - 0.7)\,] \tag{33}$$

$$C_B' = [\,C_B + \frac{(1 - C_B)(0.8D - T)}{3T}\,] \tag{34}$$

$$E = Loa * (B + T) + 0.85 Loa * (D - T) \tag{35}$$

3.3.1.2 Outfit weight

Schneekluth [1] gave the following formula for the calculation of outfit weight (W_{out});

$$W_{outfit} = k_o LB \tag{36}$$

where k_o is a coefficient based on ship types; k_o is taken as 0.028 tons/m² for inland container ships [11].

3.3.1.3 Machinery weight

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 [1]. In this study a value of 0.02 t/kW is used for the determination of machinery weight.

3.3.1.4 Margin

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.

The extent of the margin on the hull weight depends on the type and size of the ship, and importantly, on the penalty which may be exacted for non-compliance with the specific deadweight. A margin of 2% of the lightweight is recommended by Watson [9] as a margin for merchant ships.

3.3.2 Ship deadweight

The deadweight (Dwt) is a notation of the ship carrying capacity. The deadweight includes the following items:

- Cargo weight (payload or useful load). For container ships, it is the weight of transported containers. The average weight for TEU can be assumed to be around 12 tons [12].

$$Payload = 12.0 * N_C \tag{37}$$

- Other weights such as fuel, feed water, fresh water, stores, provisions, ballast other than permanent ballast, lubricating oil, etc.

3.4 Stability module

This module deals with the calculations of the ship's vertical center of gravity and the transverse metacentric height to evaluate the initial stability. The transverse metacentric height (GM_T) can be calculated as follows:

$$GM_T = KB + BM_T - KG \tag{38}$$

The vertical center of buoyancy (KB) for the Nile ships can be calculated according to the following equation [13]:

$$KB = 0.535 * T \tag{39}$$

In the preliminary design stage, the transverse metacentric radius (BM_T) can be calculated according to the following formula [6]:

$$BM_T = \left[\frac{1}{12.5 - (T/D)}\right] * \frac{B^2}{T} \tag{40}$$

The vertical center of gravity (KG) can be calculated according to the following equation:

$$KG = \frac{(W * KG)_{\text{light}} + (W * KG)_{\text{Dwt}}}{\Delta} \tag{41}$$

It is advisable to create a margin of stability with the weight margin by placing the center of mass of the margin weight at around 1.2 KG above the keel [1].

The center of gravity of each weight components can be calculated according to the following equations [1]:

$$KG_{\text{steel}} = 0.70 * D \tag{42}$$

$$KG_{\text{out}} = 1.20 * D \tag{43}$$

$$KG_{\text{m/c}} = 0.60 * D \tag{44}$$

3.5 Cost module

Many attempts and approximations have been previously proposed for the economic evaluation of ships under construction. The most famous of these attempts were the formulae proposed by Benford [14]. Although these formulae were derived during the 60 s, they still nowadays represent a good guidance, if some of the involved parameters are re-adjusted. These formulae have been used after some modifications in the FIRST project conducted in the Aerospace and Ocean Engineering Department at *Virginia University* and have proven their validity [7].

In this project, the man-hours assumed by Benford [14] have been multiplied by 0.4 for the technological enhancements in the yard standards and the price of materials. Labour costs were updated according to the current market price in USA at that time. In this work, the number of man-hours is kept as assumed by Benford [14] and the labour cost is considered 20 LE/hr according to the current market price in Egypt [11].

3.5.1 Capital cost estimation

Ship capital Cost (P) is broken down into steel cost (C_{steel}), outfitting cost (C_{out}) and machinery cost (C_{mc}). Each of these constitutes costs for material and labour.

$$P = C_{\text{steel}} + C_{\text{out}} + C_{\text{mc}} \tag{45}$$

The ship capital cost can be converted to uniform annual amounts using the capital recovery factor (CR).

3.5.1.1 Steel cost

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.

3.5.1.2 Outfitting cost

The outfitting costs (C_{out}) may be divided into outfitting labour cost and outfitting material cost. These costs can be estimated using the following formulae [7]:

$$C_{\text{olab}} = C_{\text{mh}} * f_{\text{olab}} * \left[\frac{W_{\text{out}}}{100}\right]^{0.9} \tag{46}$$

$$C_{\text{omat}} = f_{\text{omat}} * W_{\text{out}} \tag{47}$$

3.5.1.3 Machinery cost

The machinery costs (C_{mc}) may be divided into machinery labour cost and machinery material cost.

These costs can be estimated using the following formulae [7]:

$$C_{\text{mclab}} = C_{\text{mh}} * f_{\text{mclab}} * \left[\frac{SHP}{1000}\right]^{0.6} \quad (48)$$

$$C_{\text{mcmat}} = f_{\text{mcmat}} * \left[\frac{SHP}{1000}\right]^{0.6} \quad (49)$$

3.5.2 Annual operating costs

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 as follows:

$$\left[C_{\text{ao}}\right]_n = C_{\text{ao}} * 1.05^{n-1} \quad (50)$$

$$C_{\text{tao}} = \sum_{n=1}^{N} \left(\left[C_{\text{ao}}\right]_n * (\, pw - i\,\% - n\,) \right) \quad (51)$$

$$(\, pw - i\,\% - n\,) = \left(\frac{1}{(1+i)^n} \right) \quad (52)$$

3.5.2.1 Crew cost

The two major factors which determine crew costs today are crew numbers and the nationality of different sections of the officers and crew. The crew cost (C_{wages}) may be calculated according to the following formula:

$$C_{\text{wages}} = N_{\text{crew}} * \left(12 * A_{\text{wage}}\right) \quad (53)$$

3.5.2.2 Victualling cost

Victuals 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:

$$C_{\text{Vict}} = C_{\text{day}} * N_{\text{crew}} * 350 \quad (54)$$

3.5.2.3 Maintenance and repair costs

The maintenance and repair costs (C_{mar}) may be calculated according to the following equations [7]:

$$C_{\text{mar}} = C_{\text{hmar}} * C_{\text{mmar}} \quad (55)$$

$$C_{\text{hmar}} = 600000 * \left(\frac{L * B * D}{100000}\right)^{2/3} * 1.4 \quad (56)$$

$$C_{\text{mmar}} = 60000 * \left(\frac{SHP}{1000}\right)^{2/3} * 1.4 \quad (57)$$

3.5.2.4 Insurance cost

Insurance cost is directly related to the capital cost of the ship with the insurance history of the managing company exercising it as a secondary effect. The insurance costs (C_{insu}) may be calculated according to the following equation [11]:

$$C_{insu} = 0.11 * P \quad (58)$$

3.5.2.5 Administrative cost

Administration cost 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].

3.5.2.6 Fuel cost

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

$$C_{\text{fuel}} = FCT * F_{\text{price}} * Tn \quad (59)$$

3.5.2.7 Port expenses

The port expenses are directly related to the amount of cargo transported per year. The port expenses (C_{port}) may be calculated according to the following equation [11]:

$$C_{\text{port}} = W_{\text{cargo}} * Tn * f_{\text{port}} \quad (60)$$

3.5.2.8 Container handling cost

Container handling cost is directly related to the number of containers which are handled each year. Container handling cost (C_{ch}) may be calculated according to the following equation:

$$C_{\text{ch}} = 2 * TNc * Tn * C_{\text{hoc}} \quad (61)$$

where, the ship carrying capacity is handled two times (loading and unloading) in each trip leg.

4 Developed computer program (CACSO)

The present optimization problem is carried out by using a specially developed Visual Fortran computer program (CACSO). This program is illustrated by the flow chart shown in Figure 6. In this program the design variables (*Loa*, *B*, *D*, *T* and V_S) 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.

Table 4 **Input Data – developed program (CACSO)**
Tablica 4 **Ulazni podaci za razvijeni program CACSO**

1	Water depth (hw)	2.5 m
2	Round trip distance (Ru)	1960 km
3	River allowance (Ra)	0.05
4	Port allowance (Pa)	0.25
5	Ship life (N)	25 years
6	Scrap value (Sv)	0.10
7	Interest rate (i)	10%
8	Double bottom height (Hdb)	1.0 m
9	Max. container layer (N_{layer})	4 layers
10	Container handling rate (CHR)	12 TEU/h
11	Cost of handling one container (Choc)	50 LE/TEU
12	Port expenses per ton of cargo (Fport)	1.0 LE/ton
13	Man hour cost (Cmh)	20 LE/h
14	Number of crew (Ncrew)	8 crews
15	Average wage per person (Awage)	1500 LE/month
16	Fuel price per ton (Fprice)	1200 LE/ton
17	Specific fuel consumption (SFC)	150 gr/hp/h
18	Accommodating cost per person (Cday)	20 LE/day
19	Minimum required freight rate (RFR_{Min})	2300 LE/TEU
	It is the cost of transported one TEU by trucks through the same navigation route and it is taken as initial trial point	

Table 4 contains the input data of the developed program, while Table 5 contains the output results.

Table 5 **Output Results – developed program (CACSO)**
Tablica 5 **Izlazni podaci za razvijeni program CACSO**

Items		Developed program
Objective Function: RFR (LE/TEU)		1198.385
Design variables	Loa (m)	65.90
	B (m)	13.70
	D (m)	3.00
	T (m)	1.50
	V_S (km/h)	12.34
Block Coefficient C_B		0.896
No. of Containers	CNL (TEU)	7.0
	CNB (TEU)	5.0
	N_C (TEU)	70.0
	N_{layer} (Layers)	2.0

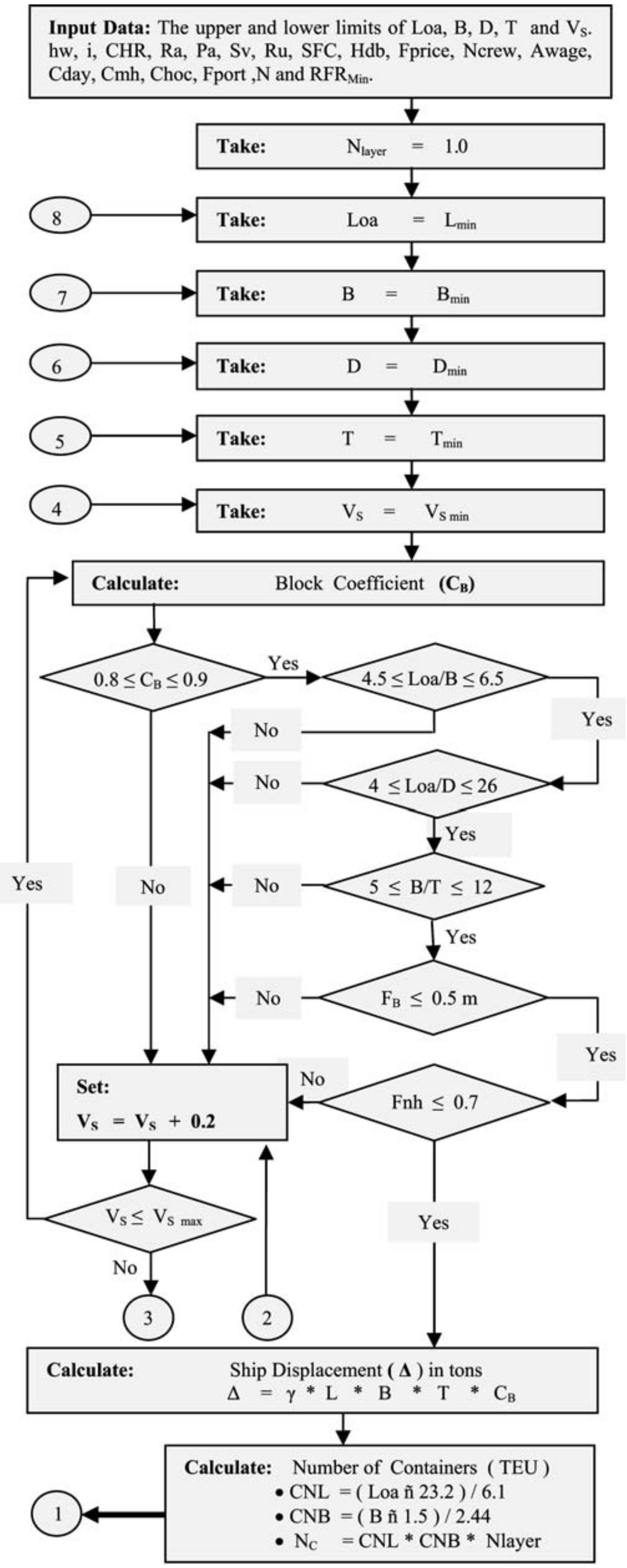


Figure 6a **The developed computer program (CACSO)**
Slika 6a **Razvijeni računalni program CACSO**

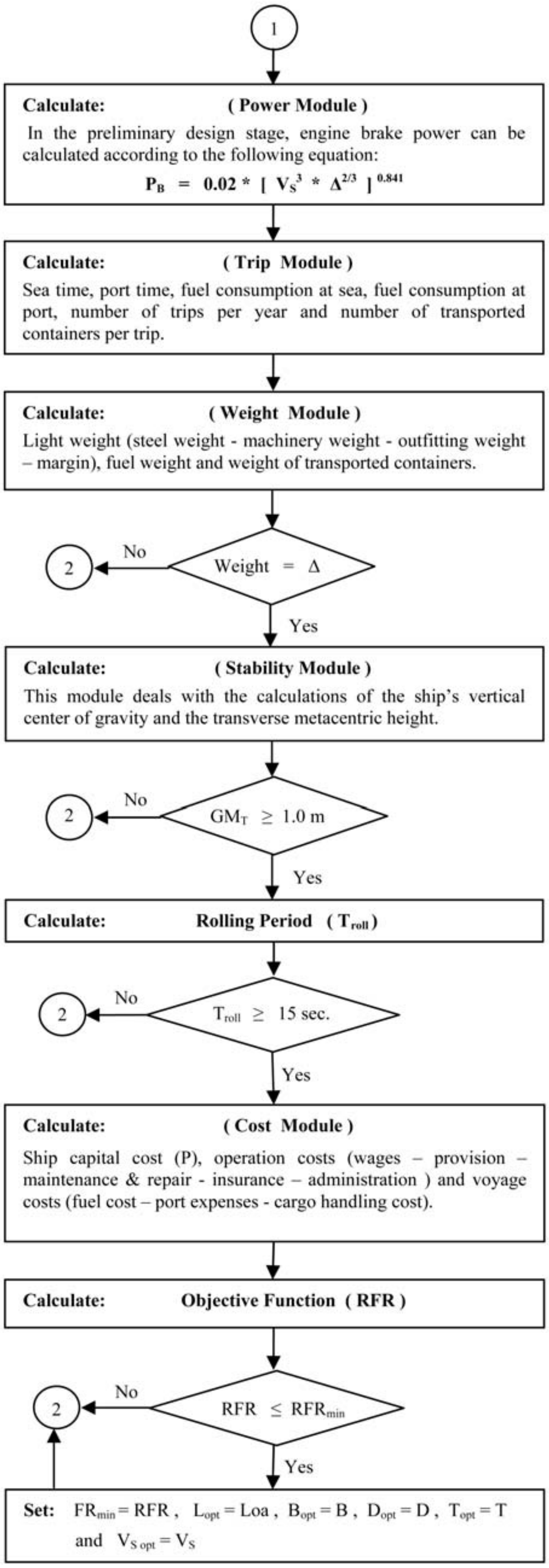


Figure 6b **The developed computer program (CACSO)**
Slika 6b **Razvijeni računalni program CACSO**

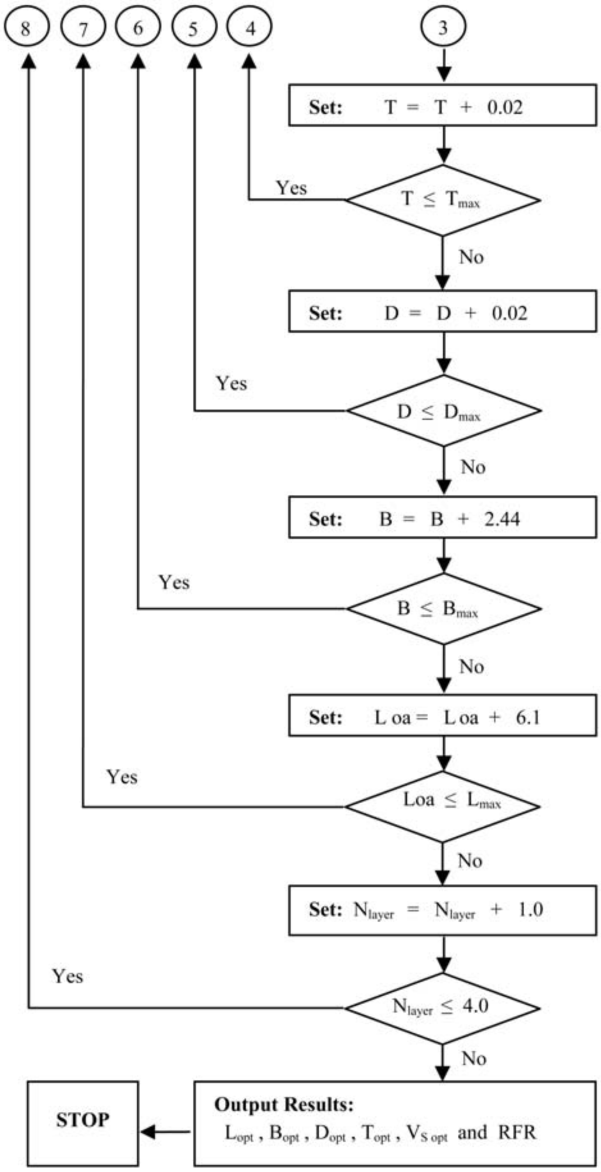


Figure 6c **The developed computer program (CACSO)**
Slika 6c **Razvijeni računalni program CACSO**

5 Analysis of the output results

From the output results of the developed computer program, one can conclude that:

1. RFR reaches its optimum value when the ship length has reached a suitable point to allocate seven containers longitudinally.
2. RFR reaches its optimum value when the ship breadth has reached a suitable point to allocate five containers transversely.
3. RFR reaches its optimum value at the lower bound of the ship depth. Any increase in the depth would increase the hull steel weight of the ship resulting in greater building costs. This might further increase the objective function.
4. RFR reaches its optimum value at the upper bound of the ship draught. However, the optimum value of the draught is achieved

by the weight balance constraint. Any increase in the draught would increase ship resistance, and this would consequently increase the required power to drive the ship at the same speed. This might further increase the objective function.

5. RFR reaches its optimum value at an intermediate point for ship speed. Figure 7 shows the variation of RFR with ship speed. This figure indicates that RFR reaches its minimum value at the lowest point in the curve. However, the optimum value of speed is achieved by Froude depth number (Fnh) constraint.

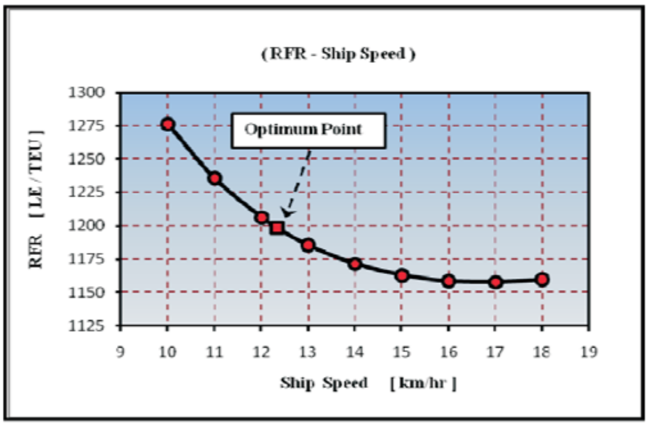


Figure 7 **Variation of RFR with ship speed**
Slika 7 **Varijacija RFR-a u odnosu na brzinu broda**

From the above mentioned points, one can conclude that the ship breadth can be increased by increasing the width of side tanks. This will cause the following effects:

- Increasing ship steel weight will consequently increase ship capital cost.
- Providing additional buoyancy will decrease ship draught and consequently, decrease the required power. Finally, the annual operating cost will be decreased.
- If the ship draught remains constant, increasing ship speed will increase the number of round trips and consequently, will increase the number of transported containers each year. From the other side, increasing ship speed will increase fuel consumption which consequently, will increase the annual operating cost.

Figure 8 indicates that the RFR reaches its minimum value at the lowest point in the curve. This point is taken as the optimum design point.

Figure 8 **Variation of RFR with side tank width**
Slika 8 **Varijacija RFR-a u odnosu na širinu bočnog tanka**

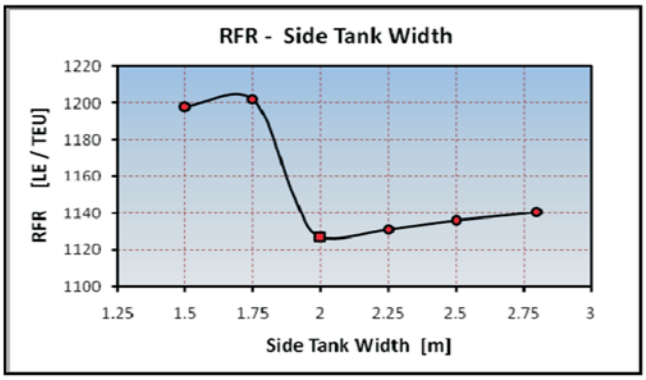


Table 6 **Effect of side tanks width on the optimum design point**
Tablica 6 **Utjecaj širine bočnih tankova na optimalnu projektnu točku**

Design	S. T. Width (m)	Loa (m)	B (m)	T (m)	D (m)	V_S (km/h)	RFR (LE/TEU)
1	1.50	65.9	13.70	1.50	3.0	12.34	1198.385
2	1.75	65.9	13.95	1.50	3.0	12.46	1202.149
3	**2.00**	**72.0**	**14.2**	**1.50**	**3.0**	**12.42**	**1127.335**
4	2.25	72.0	14.45	1.50	3.0	12.42	1131.366
5	2.50	72.0	14.7	1.50	3.0	12.38	1136.089
6	2.80	72.0	15.0	1.40	3.0	12.42	1140.411

Table 6 indicates that the increase of the width of the side tanks does not only affect the value of the objective function, but it also affects the ship design variables. From this table, design number three can be taken as an optimum design for self propelled container ships working between Cairo and Aswan through the River Nile.

Table 7 illustrates the main particulars of the optimum self propelled Cairo – Aswan container ship.

Table 7 **Main particulars of the optimum self propelled Cairo–Aswan container ship**
Tablica 7 **Glavne značajke za optimalni kontejnerski brod s vlastitim pogonom na relaciji Kairo–Aswan**

Objective Function:	RFR (LE/TEU)		1127.335
Design variables	Loa	(m)	72.0
	B	(m)	14.2
	D	(m)	3.0
	T	(m)	1.50
	V_S	(km/h)	12.42
Block Coefficient	C_B		0.896
Brake P ower	P_B	(hp)	643.28
Light Weight	W_{steel}	(tons)	301.74
	W_{out}	(tons)	27.20
	W_{mc}	(tons)	9.46
	Margin	(tons)	6.77

Table 8 and Figure 9 illustrate the distribution of containers onboard the optimum self propelled Cairo – Aswan container ship during the first and second legs for each trip.

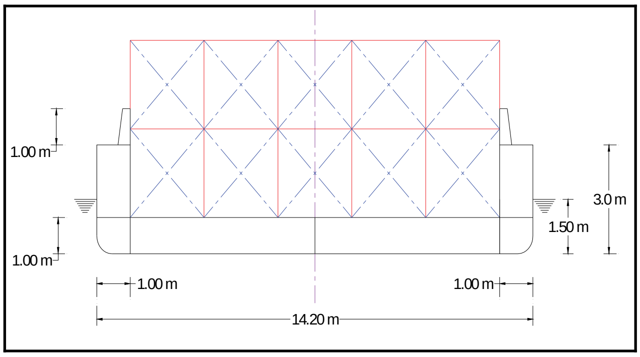


Figure 9-a **Container distribution during the first leg for each trip**
Slika 9-a **Raspodjela kontejnera za prvu dionicu svakog putovanja**

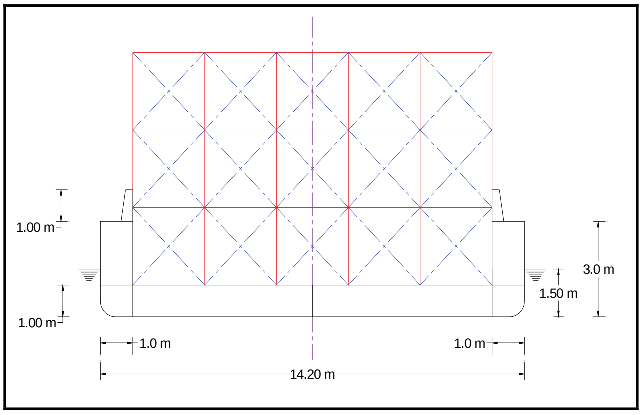


Figure 9-b **Container distribution during the second leg for each trip**
Slika 9-b **Raspodjela kontejnera za drugu dionicu svakog putovanja**

Table 8 **Container distribution for optimum Self-Propelled Cairo – Aswan Container Ship**
Tablica 8 **Raspodjela kontejnera na relaciji Kairo – Aswan**

No. of Transported Containers per Year	Tn	Trip/Year	22.5
	TNc	(TEU)	200
	Ync	TEU/Year	4500
During the First Leg 100% Full containers	Nc	(TEU)	80
	N_{layer}	(Layers)	2.0
	CNL	(TEU)	8.0
	CNB	(TEU)	5.0
	Number of Empty Containers		----
During the Second Leg 50% Full & 50% Empty containers	Nc	(TEU)	120
	N_{layer}	(Layers)	3.0
	CNL	(TEU)	8.0
	CNB	(TEU)	5.0
	Number of Empty Containers		60

6 Sensitivity study

The developed computer program (CACSO) has been used to investigate the sensitivity of the objective function (RFR) to a variety of factors to which the objective function may be sensitive.

6.1 Sailing time

The results of the developed program show that increasing sailing time per day will increase the annual number of round trips, which consequently increases the number of annually transported containers and finally decreases the required freight rate.

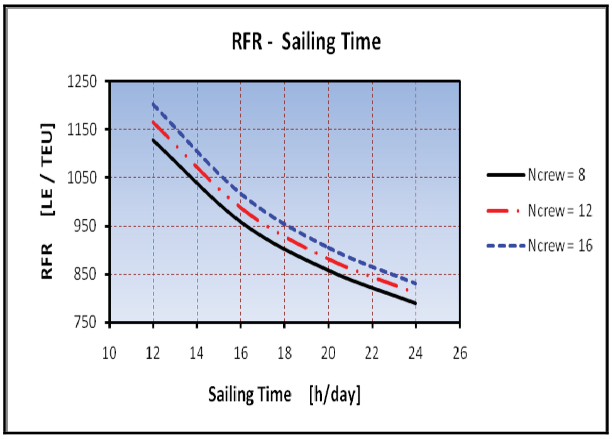


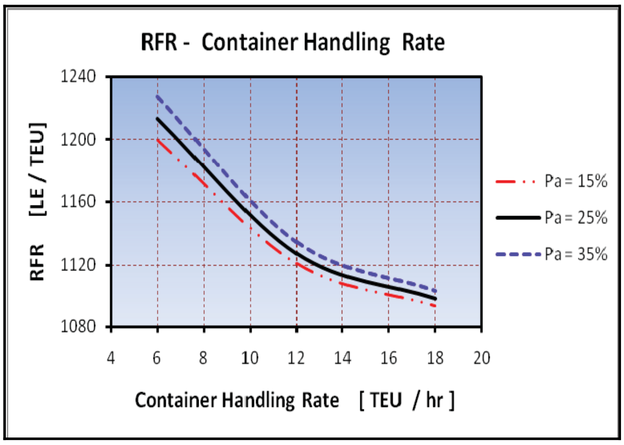
Figure 10 **Sensitivity of RFR to sailing time**
Slika 10 **Senzitivnost RFR-a na vrijeme plovidbe**

Figure 10 shows that if the sailing time increases from 12 to 24 h/day and the number of crew doubles, the required freight rate will decrease for about 25% approximately. Therefore, this navigation route must be developed to be suitable for night navigation.

6.2 Container handling rate

Port time for a container ship is inversely proportional to the efficiency of container handling equipment. It is true that the time spent in ports during which the ship is not operating in containers handling represents a loss to the ship owner.

Figure 11 **Sensitivity of RFR to container handling rate**
Slika 11 **Senzitivnost RFR-a na brzinu rukovanja kontejnerima**



It is shown from the results of the developed program that at a constant port allowance, the increasing of the container handling rate will increase the economical utility of the ship, which consequently decreases the required freight rate.

Figure 11 shows that the container handling rate has a considerable effect on the required freight rate. Therefore, the River Nile terminals must be provided with highly efficient container handling equipment.

6.3 Fuel price

The results of analyses performed using the developed program prove that at a constant fuel consumption rate, the increasing of the price of fuel will increase the operation cost, which consequently increases the total annual cost and finally increases the required freight rate.

Figure 12 shows that fuel price has a significant effect on the required fright rate. Thus, if fuel price increases 10%, the required freight rate will increase for about 4% approximately. Considering the instability of fuel prices, due to political controversies, it has been realized that fuel cost sensitivity study should have an important role in the final choice of the optimum design.

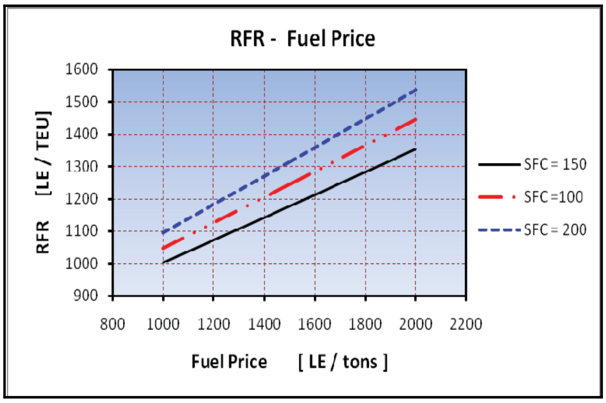


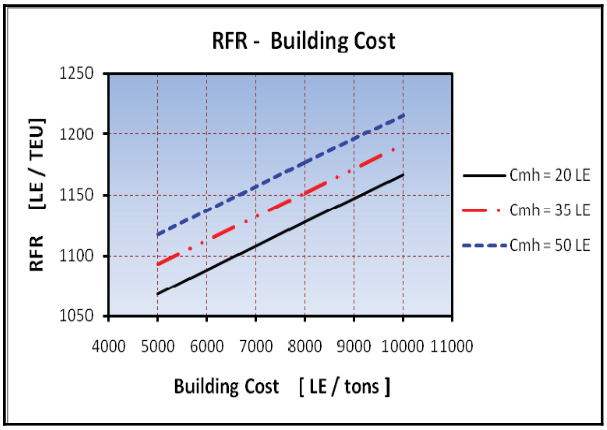
Figure 12 **Sensitivity of RFR to fuel price**
Slika 12 **Senzitivnost RFR-a na cijenu goriva**

6.4 Building cost

The results of analyses made using the developed program have proved that at a constant man hour cost, the increasing of the cost of building one ton of steel will increase the ship capital cost, which finally increases the required freight rate.

Figure 13 shows the relation between the required fright rate and the steel building cost at different man hour costs. This figure shows that the building cost has a considerable effect on the required freight rate.

Figure 13 **Sensitivity of RFR to building cost**
Slika 13 **Senzitivnost RFR-a na trošak gradnje**



7 Conclusions

1. Inland navigation offers reduction in the congestion on the Egyptian motorways and a decrease in the air pollution and overall transport cost.
2. Inland container vessel design differs significantly not only from the design of seagoing ship, but also from one waterway to another.
3. The presence of locks and bridges along the considered route, and the shallow water nature of the River Nile affect the dimensions and speed of the Nile container ships.
4. The proposed formulae for the estimation of ship steel weight and power prediction can be simply used in the preliminary design stage of conventional self-propelled inland container ships.
5. The developed computer program (CACSO) represents an accurate tool for finding out the optimum characteristics of any container ship operating between Cairo and Aswan through the River Nile.
6. The output results of the developed program may be taken as standard dimensions for any new inland container ship operating through the same navigation route.
7. The developed program (CACSO) may be simply modified to suit not only the other navigation routes but also the other River Nile ship types.
8. To enable much higher utilization of the waterways, further technical improvement and therewith further attraction for inland navigation should be created.
9. Increase in the sailing time per day through the River Nile and the use of efficient container handling equipment in river terminals will highly encourage the transportation companies to shift their activities to the River Nile transportation mode.
10. Fuel price and steel building cost have considerable effects on the required freight rate. Therefore, these costs have important roles in the final choice of the optimum design.
11. From the economical point of view, inland water transportation (IWT) mode generally remains a competitive mode of transportation even after adding the cost of secondary handling by trucks.

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Nomenclature:

AAC	Average annual cost, LE/year
A_{wage}	Average wage per person, LE/month
B	Ship breadth, m
BM_T	Transverse metacentric radius, m
CHR	Cargo handling rate, TEU/h
CNB	Number of containers abreast, TEU
CNL	Number of containers along ship, TEU
CR	Capital recovery factor
Choc	Container handling cost, LE/TEU
C_B	Block coefficient
C_{admin}	Administration cost, LE/year
C_{ao}	Annual operating cost, LE/year
C_{ch}	Container handling cost, LE/year
C_{day}	Accommodating cost, LE/day/person
C_{fuel}	Fuel cost, LE/year
C_{hoc}	Container handling cost, LE/TEU
C_{insu}	Insurance cost, LE/year
C_{hmar}	Hull maintenance and repair costs, LE/year
C_{mar}	Maintenance and repair costs, LE/year
C_{mc}	Machinery cost, LE
C_{mclab}	Machinery labour costs, LE/year
C_{mcmat}	Machinery material costs, LE/year
C_{mh}	Man hour cost, LE/h
C_{mmar}	Machinery maintenance and repair costs, LE/year
C_{olab}	Outfitting labour cost, LE
C_{omat}	Outfitting material cost, LE
C_{out}	Outfitting cost, LE
C_{port}	Port expenses, LE/year
C_{prov}	Provisions cost, LE/year
C_{steel}	Hull steel cost, LE
C_{tao}	Total annual operating cost, LE
C_{wages}	Crew cost, LE/year
D	Ship depth, m
DCS	Diesel oil consumption at sea, tons/trip
Dwt	Dead weight, tons
E	Lloyd's numeral,
FCS	Fuel consumption at sea, tons/trip
FCT	Total fuel consumption, tons/trip
FCP	Fuel consumption at port, tons/trip
Fnh	Froude depth number
F_B	Freeboard, m
F_{price}	Fuel price, LE/ton
f_{mclab}	Factor for machinery labour cost
f_{mcmat}	Factor for machinery material cost
f_{olab}	Factor for outfit labour cost
f_{omat}	Factor for outfit material cost
f_{port}	Port expenses, LE/ton
GM_T	Transverse metacentric height, m
g	Gravity acceleration, m/sec^2
Hdb	Double bottom height, m
h_w	Water depth, m
I_T	Transverse moment of inertia, m^4
i	Interest rate
K	Radius of gyration, m
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
Nc	Number of containers
N_{crew}	Number of crew
N_{layer}	Number of container layers
P	Ship capital cost, LE
PTd	Port time, days/trip
Pa	Port allowance
P_B	Brake power, hp
pw	Single present worth factor
RFR	Required freight weight, LE/TEU
Ru	Round trip distance, km
Ra	Sea allowance
SFC	Specific fuel consumption, gr/hp/h
SHP	Shaft power, hp
STd	Sea time, days/trip
Sv	Scrap value
T	Ship draught, m
TNc	Number of transported containers per round trip, TEU
TTd	Total trip time, days
TEU	Twenty feet equivalent unit
Tn	Number of trips per year
T_{roll}	Rolling period, sec
V_S	Ship speed, km/h
W_{cargo}	Cargo weight, tons
W_{light}	Light ship weight, tons
$W_{m/c}$	Machinery weight, tons
W_{out}	Outfitting weight, tons
W_{steel}	Net steel weight, tons
Ync	Number of transported containers per year, TEU/year
Δ	Ship displacement, tons
γ	Specific weight of water, tons/m^3