Parametric method of prediction of the ship operating costs

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ABSTRACT

Paper presents results of studies on a parametric method of predicting ship operating costs - useful in the preliminary ship design. Conception and theoretical basis of the method are presented, identified are also factors of significant importance for the ship operating costs, taking into account changes in the value of money. Approximation formulae for estimating the operating cost components have been developed as well as a computational algorithm based on a minimum Required Freight Rate (RFR). The useful character of the method is illustrated by examples of operating cost predictions for four different ship types designed in the Eureka project E!2772, i.e.: SINE 202 universal container carrier, SINE 203 oil product tanker, SINE 204 ro-ro ship and SINE 205 river-sea ship.

Keywords: ship design theory, ship operating costs

INTRODUCTION

In the preliminary ship design methodology formulated as an optimization problem, the aim is to determine such design solution which extremises a selected objective function (choice criterion) dependent on the sought ship parameters. The criterion measure may be a measurable ship property important for the economic effects of owner's business operations. An important element of a preliminary ship design methodology are the ship operating cost prediction methods with costs expressed as relations dependent on the design decision variables and the design mathematical model parameters.

At the time of formulation of ship design requirements, information on the future ship operation market conditions is very limited, uncertain and difficult to evaluate and any attempt to use it to perform expensive and time consuming studies aimed at optimizing the design requirements appears inefficient. Therefore, it may be justified to use simplified methods based on a small set of easy-to-get data of an index character in order to obtain approximate estimations with simple algorithms. That type of approach inspired the work on the presented method of predicting the ship operating costs by balancing the discounted costs and incomes.

The main design requirements of cargo ships, apart from the ship function, are usually: deadweight capacity **Pn** or cargo capacity **Pc**, service speed **v**, holds volume **Vc** and autonomous steaming range **R**. Results of studies on the methods of predicting ship operating costs in early stages of design, performed on different levels of accuracy of the analysed models, were frequently published, e.g. [1÷11]. Taking into account a greater number of model parameters leads to problem formulations which may be solved only with complex computational systems with the use of the optimization algorithms, e.g. those described in [12÷14].

PROBLEM FORMULATION AND ASSUMPTIONS

A problem is under consideration where a ship of given deadweight capacity **Pn**, to be operating on a route of given length **R**, calls during trip at **s** ports for loading or unloading and it should achieve an assumed rate of return **e** during **m** years of ship operation. The required freight rate **RFR** is sought that would be a minimum rate in given technical and economic conditions of ship operation but would cover all the ship operating costs taken into account in the model.

Cargo supply in ports is generally of a stochastic character, particularly in the tramp shipping. A simplifying assumption is adopted in the method, allowing to use a deterministic model in the considered line shipping case. The stochastic character of cargo supply is provided for in an indirect way by introducing a coefficient **ε**, expressing an average use of ship cargo capacity, which with sufficiently long ship operation periods allows to approximate an actual mean cargo supply. An advantage of this approach is easy way of determining the coefficient, e.g. by analysis of the log-book records of ships operating on a given shipping line.

The Required Freight Rate (**RFR**) is a rate that the owner should obtain in order to ensure the assumed rate of return **e** (with the borne ship investment and operating costs) in the ship operating period of **m** years.

The choice of **RFR** as a measure of covering the ship operating costs is based on reasoning that with an established level of actual freight rates on a given line, the best profitability will achieve a ship with the lowest required freight rate. If the future actual freight rates will be higher than the determined minimum freight rate **RFR** then the real rate of return **e*** will be higher than the assumed rate **e**, and if the opposite occurs then investment will not bring the assumed rate of return **e**. According to Schneekluth [9], in real operating conditions a minimum freight rate ship offers the greatest probability of achieving the required rate of return on shipping investment.

INVESTMENT COSTS

We assume, as in [11], that the total ship building cost **J** consists of the propulsion system cost **Js**, dependent only on the ship speed, and of other investment costs **Jp**, dependent on the ship size expressed by the deadweight capacity:

$$J(Ne, Pn) = Js(Ne) + Jp(Pn) \tag{1}$$

According to [3], the **Js** and **Jp** costs are functions dependent mainly on the installed horse power **Ne** and deadweight capacity **Pn** and the functions are increasing slower than linear functions :

$$\begin{aligned} Js(Ne) &= Cs \cdot Ne^{2/3} \\ Jp(Pn) &= Cp \cdot Pn^{2/3} \end{aligned} \tag{2}$$

In this study, the **Cs** and **Cp** constants in expressions (2) were determined by the method described in [15].

SHIP ANNUAL CARGO CAPACITY (ACC)

The Annual Cargo Capacity (**ACC**) of a ship operating, on average, **Z** days in a year, is determined as proportional to the ship cargo capacity and the number of trips in a year, with averaging capacity usage coefficient $\varepsilon < 1$:

$$ACC = n \cdot \varepsilon \cdot \lambda \cdot Pn \tag{3}$$

where λ is a deadweight usage coefficient :

$$\lambda = \frac{Pn - Pz}{Pn} \tag{4}$$

where **Pz** means the weight of stores.

The number of trips in a year **n**, with calling at **s** ports and the route length **R**, is expressed by :

$$n = \frac{Z}{T} = \frac{Z}{\beta \cdot Tm} = \frac{Z \cdot v}{\beta \cdot R} \tag{5}$$

where **T** means duration of one trip and **Tm** is the actual sailing time in one trip.

The $\beta > 1$ coefficient is a correction taking into account the T_j times of reloading operations and roadstead waiting time in one trip :

$$\beta = \frac{T}{Tm} = \frac{Tm + \sum_{j=1}^{s} T_j}{Tm} \tag{6}$$

The value of β coefficient depends on the conditions on a given shipping line, number of ports, cargo handling efficiency etc.

SHIP ANNUAL OPERATING COSTS (AOC)

Taking the ship operating cost analysis [1] and [9] as a basis, it has been assumed that the ship Annual Operating Cost (**AOC**) depends mainly on the fuel cost. In order to simplify the model, it was assumed that the average annual cost of lubricating oil and power plant repairs (dependent on the engine power) would be taken into account as a correction coefficient $\mu > 1$; then the annual operating costs are expressed as :

$$AOC = \mu \cdot n \cdot Tm \cdot Cj \cdot Gj \cdot Ne \tag{7}$$

Cj means unit fuel price [\$/t] and **Gj** means unit fuel consumption [t/(kW·h)].

Therefore, the annual ship operation cost is :

$$AOC = \mu \cdot n \cdot Tm \cdot Cj \cdot Gj \cdot \left(\frac{\varepsilon \cdot \lambda \cdot Pn}{\eta} \right)^{2/3} \cdot \frac{v^3}{Ca} = Kc \cdot n \cdot R \cdot Pn^{2/3} \cdot v^2 \tag{8}$$

where **Kc** means a respective product of parameters.

DISCOUNTED AVERAGE ANNUAL COST (AAC)

With the required annual investment rate of return **e** and assumed **m** years of ship operation, the discounted Average Annual Cost (**AAC**) – operating cost and investment cost – is expressed as follows :

$$\frac{AAC}{CRF(e,m)} = J + \frac{AOC}{CRF(e,m)} \tag{9}$$

where **CRF** means Capital Recovery Factor. With the investment rate of return **e** and **m** years of ship operation, the **CRF** is determined from the formula :

$$CRF(e,m) = \frac{e(1+e)^m}{(1+e)^m - 1} \tag{10}$$

If a predicted rate of inflation **i** and the owner's income tax (on the profit calculated as a difference between the freight incomes and operating costs) rate **t** are to be taken into account in the model, then the Capital Recovery Factor formula will be :

$$CRF^*(e,m,i,t) = \frac{(e+i)(1+e+i)^m}{\left[(1+e+i)^m - 1\right](1-t)} \tag{11}$$

In such case, **CRF*** should be inserted in all the formulae containing the **CRF** expression.

The discounted average annual cost is :

$$AAC = J \cdot CRF(e,m) + AOC \tag{12}$$

MINIMUM REQUIRED FREIGHT RATE (RFR)

If the **AAC** is covered by continuous incomes from the cargo transport freight rate during the year then the rate of return **e**, as assumed in the **CRF**, is achieved with that freight rate.

The required freight rate may be calculated from the required freight income to cover the **AAC** and the Annual Cargo Capacity (**ACC**) :

$$RFR = \frac{AAC}{ACC} \tag{13}$$

After respective substitutions and transformations, an explicit relation is given between the required freight rate and the constants and variable parameters of the model :

$$RFR = \frac{R}{Pn^{1/3}} \cdot \left[\frac{\beta \cdot CRF(e,m)}{\varepsilon \cdot \lambda \cdot Z} \left(Cp \cdot v^{-1} + \frac{Cs}{\eta^{4/9} \cdot Ca^{2/3} \cdot Pn^{2/9}} \cdot v \right) + \frac{\mu \cdot Cj \cdot Gj}{\eta^{2/3} \cdot \varepsilon^{1/3} \cdot \lambda^{1/3} \cdot Ca} \cdot v^2 \right] \tag{14}$$

As all the factors and components of this equation have positive values, their impact on the minimum required freight rate may be evaluated in a simple way.

EXAMPLES OF THE RESULTS OF SHIP OPERATING COST PREDICTIONS

The following table contains technical and economic parameters of the ships designed in the Eureka project E!2772, which were used to perform the ship operating cost predictions with the method described here.

EVALUATION OF RESULTS AND CONCLUSIONS

An impact of some model parameters on the predicted operating cost is intuitively obvious. However, the obtained analytical relations allow to analyse the impact determined by the index exponents of parameters in the model. The following observations and conclusions may be drawn from the analysis :

- increased **RFR** means higher ship operating costs
- increased required rate of return **e** – expressed by increased **CRF** – implies higher **RFR**

Table. *Design parameters and operating cost predictions of the project ships, in US dollars*

RESULTS OF SHIP OPERATING COST PREDICTION SIMULATIONS	Symbol	Unit	SINE 202 950 TEU 8 550 DWT Container carrier	SINE 203 14 300 DWT Product tanker	SINE 204 7 400 DWT Ro-ro ship	SINE 205 2 950 DWT River-sea ship
Assumed ship deadweight capacity	Pn'	[t]	8 550	14 300	7 400	2 950
Price of a reference ship	J	[$]	12 708 330	12 170 670	23 063 402	3 544 370
Price of a reference power plant	Js	[$]	5 228 790	4 330 630	7 666 479	1 447 350
Power of a reference ship engine	Ne	[kW]	11 200	10 000	19 520	3 640
Displacement of a reference ship	D	[t]	15 600	19 922	15 850	3 938
Speed of a reference ship	v	[kn]	18.5	14	20	12
Deadweight capacity of a reference ship	Pn	[t]	8 550	14 300	7 400	2 950
Cargo capacity efficiency coefficient	ε	[-]	0.85	0.85	0.85	0.85
Deadweight efficiency coefficient	λ	[-]	0.9	0.9	0.9	0.9
Number of operating days in a year	Z	[days]	340	340	340	340
Trip time to sailing time ratio	b	[-]	1.1	1.1	1.1	1.1
$\frac{\text{Cost (fuel+repairs+lub. oil)}}{\text{Cost (fuel)}}$	g	[-]	1.4	1.4	1.4	1.4
Fuel price	Cj	[$/t]	200	200	200	200
Unit fuel consumption	gj	[g/kWh]	170	170	170	170
Rate of return	e	[-]	0.06	0.06	0.06	0.06
Number of years of ship operation	m	[-]	20	20	20	20
Tax rate	t	[-]	0.18	0.18	0.18	0.18
Average annual inflation rate	i	[-]	0.03	0.03	0.01	0.03
Steaming range	R	[nm]	10 000	6 000	8 000	4 000
Assumed ship speed	v	[kn]	18.5	14	20	12
Required Freight Rate	RFR	[$/t]	75.8	24.2	80.2	50.8
Number of trips in a year	n	[-]	14	17	18	22
Investment cost	IC	[$]	12 708 329	12 170 666	23 063 402	3 544 373
Discounted annual fuel cost	FC	[$]	3 307 984	2 953 557	5 765 344	1 075 095
Discounted annual cargo handling cost (10 $/t)	HC	[$]	1 795 257	3 787 056	2 099 716	1 004 459
Discounted Average Annual Cost	AAC	[$]	6 800 989	8 366 532	10 519 965	2 553 058
Annual Cargo Capacity	ACC	[t]	89 763	189 353	104 986	50 223

- technical progress, characterised by better ship resistance--propulsion efficiency and expressed by greater **Ca** coefficient, causes decrease of **RFR**
- impact of the ship deadweight capacity **Pn** on **RFR** is ambiguous. For specific conditions of a task, the final effect depends on relations of the remaining model parameters and constants
- the increase of efficiency factors in the model causes reduction of the required minimum freight rate, i.e. reduces the operating costs
- increased ship hull and equipment prices cause increase of **RFR**
- increased fuel price **Cj** implies increased **RFR**
- technical progress in the engine design, leading to reduction of the unit fuel consumption **Gj,** decreases **RFR**.

The presented ship operating cost prediction method analyses the cost as dependent on a number of factors. The studies presented in this paper were performed with average values of the factors, as given in the Table summarizing the operating cost simulation calculations. The obtained results should therefore be read together with the respective parameter values, which reflect the current and future technical and economic relations.

NOMENCLATURE

Ca - Admiralty coefficient
Cp - other cost coefficient
Cs - installed power plant cost
e* - real rate of return
Gj - unit fuel consumption
Jp - other investment cost
Pc - cargo capacity
Pz - weight of stores
s - number of ports for reloading in one trip
T - duration time of one trip
T_j - time of reloading operation in one trip
Tm - duration of one way voyage
Vc - volume of holds
β - waiting time correction coefficient
η - deadweight/displacement ratio
λ - deadweight usage coefficient
μ - correcting factor for operating costs

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