SERĐO KOS, D.Sc.
Sveučilište u Rijeci
Pomorski fakultet u rijeci
Studentska 2, 51000 Rijeka, Republika Hrvatska
E-mail: skos@brod.pfri.hr

PRODUCTIVITY OF FULL CONTAINER SHIP AND ENERGY-ECONOMY OF ITS PROPULSION PLANT

ABSTRACT

The paper offers some clear-cut equations and coefficients expressing the basic forms of productivity of the container carrier in service: specifically, the productivity of TEU-capacity, the tonnage productivity and transportation efficiency of the container ships. In addition, the power economy of the container ship's propelling plant is being analysed from the viewpoint of transportation engineering and an equation is introduced that enables us to establish the degree of transport economy of the container ship.

KEY WORDS

container ship, productivity, energy economy

1. INTRODUCTION

At today's stage of development of science and technology the measures taken and procedures followed to improve and optimize the containers carriage are aimed primarily at a greater and more efficient utilization of the present container capacity and an increase of transportation efficiency. Hence, there is a close relationship among the measures underlying the productivity of the container carriage. Such measures are mainly directed to maximum utilization of the TEU-capacity of the container ship.

The objective of this paper is to state numerically, i.e. by means of equations, the basic forms of productivity of the container ship, the transportation efficiency, and energy economy of the container ship's propulsion plant.

2. CONTAINER SHIP'S TEU - CAPACITY

The service efficiency of the container carrier can be established on the basis of productivity of the container ship's TEU - capacity expressed in the following equation:

$$P_{TEU} = \frac{D}{C} \tag{1}$$

where:

P_{TEU} – productivity of the container ship's TEU-capacity,

D – annual, semi-annual or quarterly amount of carried containers, in TEU-units,

C – TEU- capacity of container's ship.

3. CONTAINER SHIP'S TRANSPORTATION EFFICIENCY

The productivity of the container carrier's transportation efficiency is expressed by the equation:

$$P_{TU} = \frac{R}{D_W} \tag{2}$$

where:

P_{TU} – productivity of container ship's transportation efficiency,

R – annual, semi-annual or quarterly efficiency of the container ship expressed in nautical tonne miles (tM),

D_W – container ship's capacity, in tonnes (DWT).

The yearly transportation efficiency of the container ship depends on its carrying capacity, navigational service speed, and the utilization level achieved in service. The above mentioned is expressed in the following equation:

$$R = D_W V_P \alpha \beta \gamma \delta Y \quad (tM) \tag{3}$$

where:

R – annual transportation efficiency of the container ship, in tM,

V_P – ship service speed, in knots,

α – coefficient of utilization of the ship's carrying capacity (t/t_{DWT}),

β – coefficient of exploitation of the ship service speed,

γ – coefficient of sailing time, i.e. the ratio of sailing time to the total time of ship voyage,

δ – coefficient of the ship's yearly utilization level, i.e. factor of service of the annual available time,

Y – annual available time, i.e. $365 \cdot 24 = 8760$ h.

The annual amount of carried cargo in tonnes can be established by the following equation:

$$G = \frac{R}{L} \quad (t) \tag{4}$$

where:

L – average distance sailed, in nautical miles (M).

On the basis of the previously expressed elements the productivity of the container ship can be defined as follows:

$$P_T = V_P \, \alpha \, \beta \, \gamma \, \delta \quad (t/t_{DWT}) \tag{5}$$

or

$$P_T = V_P \, \alpha \, \beta \, \gamma \, \delta \, Y \quad (tM/t_{DWT}) \tag{6}$$

In the above given equations the coefficient γ is of particular significance as it expresses the time of ship's stay in port emphasizing thereby the direct effect of the technology used in loading/discharging the ship.

The coefficient γ can be more accurately expressed by the relationship:

$$\gamma = \frac{T_S}{T_V} = \frac{T_S}{T_S + T_R} \tag{7}$$

where:

T_S – sailing time, in hours,

T_V – total voyage time, in hours,

T_R – time spent in "ship's stay" (ports, anchorage, etc.), in hours.

$$T_S = \frac{L}{V_P \beta} \quad (h) \tag{8}$$

$$T_R = \frac{T_{LD}}{f_{LD}} \quad (h) \tag{9}$$

T_{LD} – effective loading/discharge time, in hours,

f_{LD} – coefficient of time employed for loading/discharge against the total time of ship's stay.

$$T_{LD} = \frac{D_W \alpha}{\Delta_{LD}} \tag{10}$$

D_W – ship's carrying capacity, in tonnes,

Δ_{LD} – loading/discharge rate, in (t/h) or (TEU/h).

In virtue of the above the coefficient of the sailing time can be shown as follows:

$$\gamma = \frac{L}{L + \dfrac{D_W V_P \alpha \beta}{f_{LD} \Delta_{LD}}} \tag{11}$$

4. TONNAGE PRODUCTIVITY OF THE CONTAINER SHIP

The tonnage productivity of the container ship is practically expressed in the following equation :

$$P_T = \frac{\delta}{\dfrac{L}{V_P \alpha \beta} + \dfrac{D_W}{f_{LD} \Delta_{LD}}} Y \quad (t/t_{DW}) \tag{12}$$

The coefficient of annual service δ may occasionally reach a value of 0.95, but often this value is considerably lower. The coefficient of exploitation of service speed β depends to a large extent on the hydrometeorological conditions spanning a range from 0.75 to 0.95. The coefficient of utilization of the ship's carrying capacity α is widely dispersive ranging from 0.4 to 1.

Supposing that all coefficients are constant values - this never being the case in practice - according to equation (5) the productivity of the container ship's capacity would be directly proportional to the ship's service speed. The assumption being wrong, as in practice this never occurs for the mere reason that the coefficient γ in the equation (11) decreases with the increase of ship's speed. In addition, from the equations (11) and (12) it is possible to draw the conclusion that the productivity of the container ship's capacity is not at all unrelated to its own capacity, but that under similar conditions by increasing the ship's capacity the productivity is reduced. The annulment of the adverse effect on productivity of the ship's capacity occurring with an increase of the ship's size may be achieved only by a proportional increase in loading/discharging rate, i.e. a rate directly proportional to the container ship's size.

5. ENERGY-ECONOMY OF THE CONTAINER SHIP'S PROPULSION PLANT

The power economy of the container carrier can be generally expressed by calculating the specific motive power required to effect the sea transport. The specific motive power needed can be expressed in the following equation:

$$Q_{tM} = \frac{Q_V}{T_e} \quad (t/tM) \tag{13}$$

where:

Q_{tM} – specific motive power required for sea transport, in t/tM,

Q_V – fuel oil consumption per voyage (t/voyage),

T_e – transport rate of voyage (tM/voyage).

$$Q_V = Q_S + Q_A \quad (t/voyage) \tag{14}$$

Q_S – fuel oil consumption during navigation (t/voyage),

Q_A – fuel oil consumption for "service duties" (manoeuvring, berthing, unberthing, anchoring, etc.) (t/voyage).

$$Q_S = \sum_{i=1}^{n} \rho_i \, P_i \, T_{Si} \, 10^{-6} \quad (t) \tag{15}$$

where:

i = 1, 2, 3...n , degrees of main engine load,

ρ_i – specific fuel oil consumption at the degree of load i, in g/kWh,

T_{Si} – sailing time with degree of load i, in hours,

P_i – main engine output in kW at the degree of load i,

$$T_{Si} = \frac{L_i}{V_i}$$

L_i – length of voyage, in nautical miles with the degree of load i,

V_i – average sailing speed, in knots at degree of load i.

The effect of the different degrees of engine load in the container ship's navigation can be expressed by the following coefficient:

$$\Psi = \frac{\sum\limits_{i=1}^{n} \rho_i P_i \frac{L_i}{V_i}}{\rho P_N \frac{L}{V_P}} \tag{16}$$

where:

Ψ – coefficient of propulsive efficiency of the container ship,

ρ – nominal specific consumption of fuel oil, in g/kWh,

ρ_I – specific fuel oil consumption at degree of load i,

P_N – nominal main engine output, in kW,

P_i – main engine output, in kW at degree of load i,

L – total distance sailed, in M,

L_i – leg of voyage with degree of load i in nautical miles,

V_i – average ship's speed at degree of engine load i, in knots,

V_P – ship's service speed, in knots.

The effect of fuel oil consumption for "service duties" can be expressed by the following coefficient:

$$\partial = \frac{Q_S + Q_A}{Q_S} \tag{17}$$

The coefficient of fuel oil consumption ∂ indirectly covers the coefficient of sailing time γ. At lower values of the coefficient γ the fuel oil consumption for "service duties" has a relative higher significance than at higher values. Hence it follows that the coefficients ∂ and γ are reciprocal in inverse proportion.

The fuel consumption per voyage can be expressed in the following equation:

$$Q_V = Q_S \, \partial \text{ (t/voyage)} \tag{18}$$

and the transportation rate of the container ship can be expressed as follows:

$$T_e = D_W \, \alpha \, L \text{ (tM/voyage)} \tag{19}$$

6. DEGREE OF TRANSPORTATION ECONOMY OF THE CONTAINER SHIP

As one of the most significant factors in commercial operation of the container ship, the degree of its transportation economy can be generally expressed in the following equation:

$$E = \frac{D_W V_P}{P_N} \text{ (tM/kWh)} \tag{20}$$

The degree of transportation economy of the container ship at single legs of the voyage can be expressed in the following way:

$$E_i = \frac{D_W V_i}{P_i} \text{ (tM/kWh)} \tag{21}$$

It should be mentioned that the transport economy of the container ship is due to a great extent to the excellency of design of the ship construction and its propulsion plant. The transport economy depends as well on the specific consumption of motive power of the container ship.

7. CONCLUSION

The relevant factors affecting the productivity of the container ship in service and the energy-economy of its propulsion plant may fall into two categories:

- "technical factors" (D_W, V_P, P_N, ∂);
- "technological factors" (α, β, γ, δ, f_{LD}, Δ_{LD}, Ψ).

An increase in the container ship's size, i.e. its D_W, will have an adverse effect on the productivity of the ship's carrying capacity if it is not backed up by higher efficiency in the loading/ discharging rate or shorter time of ship's stay in a port.

A decrease in the ship's speed will result in a reduced consumption of motive power, but at the same time this will reduce the productivity of the container ship's capacity.

Substantial disproportions can be brought about at the designing stage of the container carrier when determining the ship's capacity and speed or when decreasing speed of the container carrier in service. If the power aspects are prevailing, the adverse effects may then be reduced only by shortening the time of the ship's stay in port, i.e. by considerably increasing the ship's loading/discharging rate.

SERĐO KOS, D.Sc.
Sveučilište u Rijeci
Pomorski fakultet u rijeci
Studentska 2, 51000 Rijeka, Republika Hrvatska
E-mail: skos@brod.pfri.hr

SAŽETAK

PRODUKTIVNOST POTPUNO KONTEJNERSKOG BRODA I ENERGO-EKONOMIČNOST BRODSKOG POGONA

U radu se pomoću jednadžbi i uvođenjem određenih koeficijenata iskazuju osnovni oblici produktivnosti kontejnerskog broda u eksploataciji: produktivnost TEU nosivosti, produktivnost tonaže i prijevozni učinak kontejnerskog broda. Takođe, sa stanovišta transportnog inženjerstva analizira se energo-ekonomičnost brodskog pogona kontejnerskog broda i iskazuje jednadžba pomoću koje se općenito može odrediti stupanj prijevozne ekonomičnosti kontejnerskog broda.

KLJUČNE RIJEČI

kontejnerski brod, produktivnost, energo-ekonomičnost

REFERENCES

[1] **Wohl, Martin & Brian V. Martin**: *Traffic System Analysis for Engineers and Planners,* McGraw-Hill, New York, 1967.

[2] **Benjamin, Jack R. & C. Allin Cornell**: *Probability, Statistics and Decisions for Civil Engineers,* McGraw-Hill, New York, 1970.

[3] **Baerwald, John E., Mathew J. Huber & Louis E. Keefer**, eds.: *Transportation and Traffic Engineering Handbook,* Institute of Traffic Engineers, Prentice-Hall, Englewood Cliffs, NJ, 1976.

[4] **Pearson, Roy**: *Container ship and shipping,* Fairplay Publications Ltd., London, 1988.

[5] **Schumer, Leslie A.**: *The Elements of Transport,* Butterworths, Sydney, 1974.

[6] **Edward K. Morlok**: *Introduction to Transportation Engineering and Planning,* McGraw-Hill, New York, 1978.

[7] **Pignataro, Louis J.**: *Traffic Engineering: Theory and Practice,* Prentice-Hall, Englewood Cliffs, NJ., 1973.