THEORETICAL ANALYSIS OF COST EFFICIENCY OF GENERAL CARGO TRANSPORTATION ON CONTAINER FEEDER LINES IN THE BLACK SEA REGION

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Abstract: *The present paper analyses the concept of efficiency in general cargo transportation on container feeder lines in the Black Sea region. The components and organization of vessels' voyages in feeder services, technical and economic parameters of deployed vessels as well as the structure of liner shipping costs are defined. Factors affecting efficiency are analyzed in detail and current means for decrease of liner shipping costs are presented.*

Keywords: CONTAINER FEEDER LINES, FEEDER SERVICES STRUCTURE, LINER SHIPPING COSTS, EFFICIENCY INDICATORS

1. Introduction

The concept of efficiency in general cargo transportation on container feeder lines in the Black Sea region is an important issue subject to analysis and optimization. As feeder shipping services incur high levels of costs, it is vital for liner operators to apply various methods for monitoring and minimization of costs levels given the presently unstable cargo volumes. The components and organization of vessels voyages in feeder services in the region, technical and economic parameters of feeder containerships as well as the structure of liner shipping costs are defined as parameters for defining the cost price function. Factors affecting efficiency are analyzed in detail and their effect on cost efficiency is outlined.

2. Voyage structure and deployed tonnage characteristics of container feeder lines in the Black Sea region

The structure of feeder transportation services in the region comprises several stages. The first stage corresponds to all operations as from containers positioning at the terminals till the moment the designated vessel sails off the port. The second stage includes all operations for the transportation of containers by sea by the servicing feeder vessels. All operations as from the moment of ships arrival at next port of the line for loading/unloading of containers are elements of the third stage of the feeder liner voyage.

Liner operators control the transportation process and bear all costs for its implementation. The most important temporal scope for analysis and monitoring as concerns costs efficiency are the stages between the positioning of containers at terminals till the moment of unloading of containers from ships at the terminals. Such focus on these particular stages of the liner shipping supply chain is related to the fact that fleet operations and the implementation of the transportation process are influenced by a number of stochastic factors which affect the overall efficiency of the container feeder services transportation process. Therefore liner operators are focusing on costs minimization in order to achieve efficiency on these stages of the liner shipping supply chain as maritime transportation is the main activity of liner companies despite trends for liner shipping supply chain integration.

Liner shipping voyages of feeder lines in the Black Sea region are specific in structure as ships ply between a predefined sequence of ports situated within a short distance by sea. Offering short transit times is a competitive factor in liner shipping, in particular when the goods involved are time sensitive [2]. Furthermore, the configuration of feeder routes in the region stems from the geographical position of the mainstream hub ports which are based in the Mediterranean region. The structure of the feeder vessels voyage can be divided into several stages:

- arrival of ships for loading and unloading of containers at ports of the service according to the set schedule, followed by pilotage, berthing, mooring and inward formalities;
- port stay of ships for cargo handling operations;
- departure from the feeder port, including outward formalities, unmooring, pilotage, sailing off the port limits;
- operations for ships navigation to the next port of call on the feeder line.

The abovementioned process is repeated within the round voyage of the vessel. We can determine that feeder voyages are of the multi-transitive cyclic type. Each voyage comprises minimum of two or more transits between feeder ports and the voyage begins and ends at the first port of the feeder line which is typically a hub port on a mainstream line operated by the same liner operator. Thus the beginning of the feeder voyage is the moment of arrival at the first port of the feeder line. The voyage ends at the moment the ship arrives at the first port after having completed a full cyclic voyage. The usual frequency of feeder services in the region is weekly which means that every seven days a feeder vessel sails off the initial feeder port of the line.

The duration of the round voyage is a sum of the total sailing time and total vessel's time at ports, measured in days of 24 consecutive hours and pro rata, according to the following formula:

$$(1)\quad T_v = \sum_{i=1}^{n} T_{si} + \sum_{j=1}^{m} T_{pj}$$

where T_v – duration of one round voyage (days); t_{si} – transit time between the ports within one round voyage and i=1,2….n, n - number of transits between ports within one round voyage; t_{pj} – port stay time at each port and j = 1,2…m, m - number of ports on the feeder line.

Transit time in sailing between any two ports of the round voyage depends on the distance travelled and the average service speed of the ship. Vessels time at ports includes the time for cargo handling operations, auxiliary services and unplanned delays from the moment of berthing till unmooring. Ports stay time depends on the quantity of containers to be loaded/unloaded, cargo handling rates and the duration of auxiliary services. Unplanned delays are usually related to unfavorable meteorological conditions, breakdowns of cargo handling equipment, etc. It is important to define the specific components of feeder voyages in order determine the factors of transportation process efficiency as feeder vessels never sail empty and containers are being carried onboard during the entire duration of the voyage. The period of operation of each feeder vessel corresponds to the time needed to perform certain number of voyages. Basically, feeder ships are not fully operable all the year round which depends on the age and the technical condition of the vessel as well as the planned repairs. Thus if the time used for round voyages for each vessel are summed up, the figure will represent the total time in operation of the particular vessel. For the purposes of defining efficiency of feeder liner operations we seek to analyze the number of voyages performed by each vessel designated to the service within the period of operation.

Technical and economic characteristics of ships define their productivity as means of transportation. Main characteristics are all linear measures, weight and volume measures, service speed and bunker consumption. Container vessels employed on feeder services in the region are typically single-deck ships, fully-cellular, usually gearless and with a shipping capacity of up to 2500 TEU. Shipping capacity is measured in TEU (twenty-foot equivalent unit) which is a measure of ships carrying capacity in terms of the number of 20-feet containers. Linear characteristics of vessels are important for determining the compatibility with the technological limitations of ports, terminals and designated berths, such as length of berths, draft at berths, width of port channels, etc. Thus it is vital for liner operators to consider whether a vessel to be chartered in or owned would be compatible with the feeder ports of the line.

Average service speed of feeder vessels is defined as the average speed during sea passages for a certain period of time taking into account the reduction of speed during channel passages, maneuvering, pilotage, delays due to unfavorable meteorological conditions, etc. The average service speed of a 1500 TEU containership is about 19 knots. Service speed is a subject of optimization in operational planning of the transportation process in feeder liner shipping due to the exponential relation between service speed increase and bunker consumption [3]. Average service speed for the period in operation is defined as the ratio between the total distance sailed and sailing time (2)

$$(2) \qquad \boldsymbol{V_{av}} = \frac{\sum_{i=1}^{n} \boldsymbol{L_i}}{\sum_{i=1}^{n} \boldsymbol{T_{si}}}$$

Where V_{av} – average speed for the operational period (knots); L_i – distance travelled by sea for each transit between ports (nautical miles).

The ratio of utilization of ship's carrying capacity can be defined as follows [1]:

$$(3) \quad u = \frac{\sum_{i=1}^{n} Q_i \, . L_i}{\sum_{i=1}^{n} D_{teu} . L_i}$$

Where u – ratio of shipping capacity utilization for the operational period (percentage); Q_i – number of containers shipped on each intravoyage leg (TEU); D_{teu} - ship's nominal shipping capacity (TEU).

Nominal shipping capacity is the most important factor in estimating the efficiency of the transportation process as revenues are formed on the basis of number of full containers loaded. Ships' deadweight is the limitation as concerns the total weight of containers. Transportation output of feeder containerships is defined as the number of containers transported over a certain distance sailed. It depends on the nominal shipping capacity of the vessel, utilization ratio of ships capacity, average service speed and ratio between sailing time and stay time at ports.

3. Cost efficiency of general cargo transportation on container feeder lines in the Black Sea region

Operation of container vessels incurs the largest value of feeder liner shipping costs.

Operational costs of ships are divided into two main groups: voyage costs and running costs. Ships' running costs are fixed costs and are generated regardless of the fact whether vessels perform voyages as long as they are in operation. Vessels running costs include crew salaries, technical supplies, spare parts, provision, repairs and technical maintenance, fresh water, insurances, etc. The average level of running costs is relatively constant over a certain period of operation in accordance with the ships' budget which is usually planned on a yearly basis. Voyage costs, on the other hand, are generated specifically during performance of voyages. Voyage (variable) costs include: bunker consumption costs, disbursement accounts at ports of call, charges for passing channels, etc. Cargo costs ensue from all charges for storage of containers at terminals, terminal handling charges, etc. All cargo costs depend directly on the rate of containers arrival at the terminals. Costs related to containers also depend on the cargo handling operations at ports and on storage costs paid by the liner operator at each terminal [3]. These costs are basically determined in the official port tariffs and, as a rule, full containers are charged for storage and the longer the storage time the higher the storage charges at container terminals for the operators. Other costs include administration costs related to personnel costs and costs for management of the transportation process.

Due to high levels of direct costs related to feeder operations, the primary objective of liner operators is to achieve minimum total cost for the operational period by determining the optimal duration of the round voyage and the optimal fleet size basis the assumption that container arrival is stochastic. Besides, cost of containers dwell time and handling time at the terminals influences the optimal frequency of the feeder service and fleet size.

In this study we consider a feeder line in the Black Sea region with six ports, short distances by sea between ports and containers arriving according to a Poisson rate with parameter λ_i which represents the arrival rate of containers at each port. The arrival rates at the different ports of the feeder line vary. We assume that all costs are borne by the liner operator. The size of containers is assumed to be equal to TEU. Ships capacity is measured in terms of the total number of TEUs the ship can carry. Further assumptions are related to the size of the vessels as we also assume that the fleet is composed of ships of same size with same voyage costs. The developed cost function has two variables: the total round voyage time T_v within the operational period and the size of the fleet K. We have to prove that there is an unique value of T_v that minimizes the total cost for the period in operation. The expected total cost for the operational period can be formulated as follows:

$$(4) \; TC_{op} = \frac{T_{op}.K}{T_v}\left[\left(\sum_{j=1}^{m} C_j \, \lambda_j\right)\frac{T_v{}^2}{K^2} + VC_{op}\right] + K.FC_{op}.T_{op},$$

Where TC_{op} – total cost for the operational period; T_{op} – duration of the operational period; VC_{op} – variable costs per round voyage; K - number of vessels designated to the service; C_j – costs for containers dwell time and handling time at each port; λ_j – container arrival rate at each port. We can further simplify expression (4) as follows:

$$(5) \; TC_{op} = T_{op}\left[\left(\sum_{j=1}^{m} C_j \, \lambda_j\right)\frac{T_v}{K} + \frac{VC_{op}.K}{T_v}\right] + K.FC_{op}.T_{op},$$

The elements of the cost function represent the cost of delay of containers at the terminals of the feeder line until loaded based on the container arrivals rate at each port during T_v, total voyage costs for the operational period for all deployed vessels and the total running costs for all feeder vessels during the operational period.

It is evident from (5) that if we keep at minimum the dwell time of containers at ports and minimize the port stay time of vessels we can achieve minimization of total costs for the operational period. Thus we have to prove that TC_{op} is a convex function of T_v:

(6) $\frac{\partial TC_{op}}{\partial T_v} = T_{op}\left(\frac{1}{K}\sum_{j=1}^{m} C_j\,\lambda_j - \frac{VC_{op}.K}{T_v^2}\right)$,

and

(7) $\frac{\partial^2 TC_{op}}{\partial^2 T_v} = \frac{2T_{op}.VC_{op}.K}{T_v^3}$,

Since (7) has a positive value for a positive T_v, we can assume that there is an unique duration of the round voyage T_v that minimizes the total costs for the operational period (Figure 1).

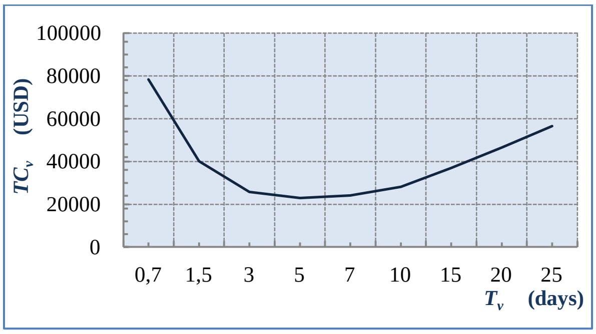

Figure 1. *Total costs as a function of voyage time*

The optimal value of T_v occurs when:

(8) $\frac{\partial TC_{op}}{\partial Tv} = T_{op}\left(\frac{1}{K}\sum_{j=1}^{m} C_j\,\lambda_j - \frac{VC_{op}.K}{T_v^2}\right) = 0$,

which is equal to:

(9) $T_v' = K\sqrt{\frac{VC_{op}}{\sum_{j=1}^{m} C_j\,\lambda_j}}$,

where T'_v is the optimal voyage time. Since optimal voyage time is also a function of the size of the fleet *K*, we should analyze the intervals between ships departure from the initial feeder line port. The intervals between ships departure from the initial port should be minimized, i. e. the frequency of service should be increased. This means that voyage time should be shorter and fleet size should be larger. As per (5), however, more ships will increase the total cost, therefore the fleet size should also be kept at minimum. Assuming that if the round voyage can be completed in

(10) $\sqrt{\frac{VC_{op}}{\sum_{j=1}^{m} C_j\,\lambda_j}}$

time units, the optimization decision is to employ only one vessel on the line which means that the interval between ship departures from initial port should be kept at same time units as per (10) to minimize total costs. On the other hand, the minimum number of ships is a function of the voyage time. When the minimum actual voyage duration is higher than the optimal voyage time, the operator should aim at keeping the voyage time at minimum and define the optimal fleet size as per the derived value of *K*.

The cost price of the transportation process is a complex parameter showing the monetary value for production of one unit of transportation output. Unit cost per TEU is the ratio between total costs for the operation period and volume of transportation output (number of TEUs carried). The cost for the transportation of one TEU as from the container positioning at the terminal till the moment of container unloading from the vessel at the port of destination can be defined as:

(11) $C_{teu} = \frac{T_{op}\left[\left(\sum_{j=1}^{m} C_j\,\lambda_j\right)\frac{T_v}{K} + \frac{VC_{op}.K}{T_v}\right] + K.FC_{op}.T_{op}}{u.K.D_{teu}}$,

Where *u* is defined as per (3).

The efficiency in liner shipping operations is defined as performing of the transportation process at minimum total cost for the operational period. The level of total costs depends on various factors. As presented many of these factors can be controlled and liner operators can fully manage the efficiency of the transportation process.

4. Conclusion

Based on the performed observations, as total costs increase, other parameters constant, the optimal voyage time increases which is due to the service speed of the ships. If costs of the dwell time and handling time of containers at ports is altered, other parameters constant, the optimal voyage time decreases. The latter is logical since the cost of keeping containers at the ports increases as dwell time increases and in this case higher frequency of service is needed. Further, we can conclude from (11) that the lower the utilization ratio of fleet shipping capacity, the higher the total cost for the operational period and vice versa. All other things being equal, the cost of transportation is lower if the rate of cargo handling operations increases. This is logical as the port stay time of vessels decreases and this leads to shorter round voyage time which, on the other hand, increases the number of voyages performed for the operational period. Increase of the number of vessel servicing the line can lead to lowering of costs through optimization of service frequency and thus decreasing the time for containers dwell time at ports.

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