Global route choice modeling for product tankers and LNG carriers using AIS data: Focusing on the Suez Canal

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This paper addresses global route choices for product tankers and liquefied natural gas (LNG) carriers, focusing on the competitive situation between the Suez Canal (SC) and its competitor, the Cape route. This paper first establishes a methodology to estimate the actual route choices for product tankers and LNG carriers, utilizing a vessel movement database and focusing on the share of SC transit for each regional pair where the cargo originates and is destined to. A disaggregated logit model is applied to predict the SC transit shares for regional pairs. Finally, the model is deployed to quantitatively evaluate the potential impacts of changes in market conditions, including fluctuations in fuel costs, time charter, and the SC tolls policies. This study provides key insights to the Suez Canal Authority on the economic impacts of toll changes and offers strategic guidance to shipping companies on route selection amid changing market conditions.

Key Words: *Global Route Choice, AIS, Suez Canal, Product tanker, LNG carrier*

1. Introduction

As global energy needs rise alongside economic development, international seaborne trade in resources has become essential to daily life. Political and economic shifts consistently alter energy supply and demand, reshaping the landscape of international maritime commerce. As maritime trade becomes more globalized, shipping companies face stiffer competition, making them increasingly attentive to costs and delivery times. Therefore, grasping global trade and transport movements and analyzing the transport route and volume of trade is crucial.

Recent advancements in information technology and satellite infrastructure have enabled access to accurate ship movement data, notably through the Automatic Identification System (AIS). AIS captures and provides real-time numerical data on global ship activities, including their transit histories, speeds, and locations. Research leveraging this data is progressing in areas like market insights, port cargo flow predictions, and ship behavior assessments.

The Suez Canal (SC), spanning 193.3 km, links Suez at the Red Sea with Port Said at the Mediterranean in Egypt. As illustrated in Fig. 1, the SC is pivotal in global logistics, offering the most direct sea passage between Asia and Europe. Vessels allowed to transit are defined as the combination of draught and width by the Suez Canal Authority (SCA).

The competitive situation of the SC differs from vessel types. The SC's major competitor for containerships is the Panama Canal (PC), mainly for the vessels connecting eastern Asia and the east coast of North America[1)]. The SC's major competitor for dry bulk carriers and tankers is the route via the Cape of Good Hope (hereafter 'Cape')[2)]. These studies analyzed the SC's current competitive situation regarding containerships and dry bulk carriers and applied an aggregated logit model to describe the route choices of shipping companies on a global scale.

Additionally, the competitive situation of tankers is more complicated than that of containerships and

dry bulk carriers because there are many types of vessels, such as crude oil tankers, product tankers, chemical tankers, and liquefied natural gas (LNG) carriers. Fig.2 displays the total volume of global tanker shipping, measured in million tons, categorized by vessel size and commodity from 2013 to 2021. Accordingly, crude oil is the most common commodity. Chai et al.[3] developed a nested logit model to estimate the route choice of crude oil tankers. Due to the restriction on vessel size imposed by the SC, the passage of larger vessels has become a challenge in response to the trend of larger vessels in maritime transport; vessels loaded over 240,000 tons cannot navigate through the SC. As represented in Fig. 2, product tankers and LNG rank second and third, respectively, in vessel type prevalence within tankers, emphasizing the importance of a dedicated route choice model for them. In particular, LNG shipping has recently increased because of rising environmental concerns and energy source shifts and thus attracted more attention[4].



Fig.1 The location of the Suez Canal route and the Cape of Good Hope route

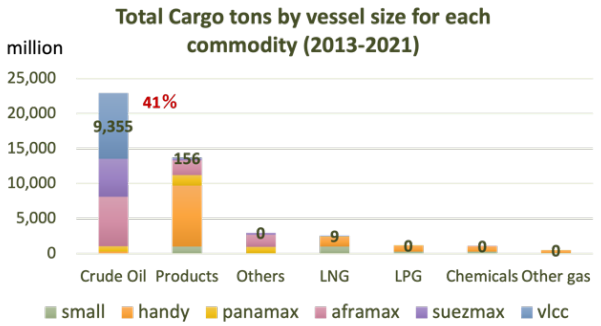


Fig. 2 Tanker shipping volume by vessel size for each commodity from 2013-2021 (source: authors made from Alphatanker)

Therefore, this paper addresses global route choices for product tankers and LNG carriers, focusing on the competitive situation between the SC and its competitor, the Cape route. This paper first establishes a methodology to estimate the actual route choices for product tankers and LNG carriers using a vessel movement database, by specifically focusing on the share of SC transit for each pair of regions where the cargo originates and is destined. Second, a logit model is applied to predict the estimated shares for regional pairs, focusing on the supply side to delineate the preferences of global shipping companies. The SC transit share is then estimated from the model to evaluate how the SC competes with other routes in the global product and LNG tanker shipping market. Finally, the model is deployed to perform several simulations that quantitatively evaluate the potential impacts of changes in market conditions, including fluctuations in fuel costs, time charter, and the SC tolls policies, on the SC transit share within the global maritime transport network. This study aims to not only deliver crucial insights to the canal administrator (i.e., SCA) regarding the economic implications of Suez toll variations but also offer actionable recommendations to shipping companies and ship owners about optimal route selection with evolving market conditions.

2. Data for Analysis

A vessel movement database provides a comprehensive grasp of the choice behavior of vessels operating worldwide. Vessel movement data, including transit information of the SC from 2013 to 2021, are acquired from the Alphatanker database provided by AXS Marine, which specializes in data for liquid bulk shipping. The Alphatanker database provides information on vessel movements, such as place names (including not only ports but also major canals and straits and some anchorages), arrival dates, and departure dates, as shown in Fig. 3. They also provide information such as the name of the vessel, International Maritime Organisation (IMO) number, callsign, dead-weight tonnage (DWT), and gross tonnage (GT) for all vessels that are AIS-equipped since the databases are currently organized based on data acquired from AIS. The data used in this analysis comprises four distinct datasets: ballast vessel movement, laden vessel movement, ballast Suez transits, and laden Suez transits.

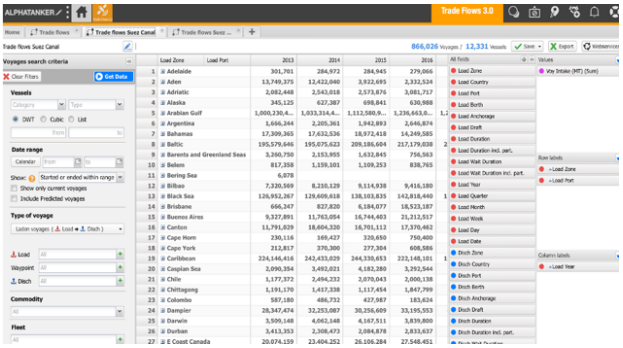


Fig.3 The example of data from Alphatanker database

3. Methodology

(1) Model formulation

This study applies a logit model to describe the route choice behavior of product tankers and LNG carriers on a global scale. The model focuses on the supply side, namely, shipping cost and time, and assumes that each shipping company chooses a vessel route based on its utility defined by route, under the condition that the demand for the product oils and LNG to be shipped is provided from one region to another.

Thus, when H_{ij} is defined as the choice set of shipping routes from region i to region j, including the routes via the SC and Cape, if a vessel chooses route h, the utility, U_{ijhm}, of route h from region i to region j for cargo m, is the greatest relative to the utilities, $U_{ijh'm}$, of any other route h', as shown in Equation (1).

$$U_{ijhm} > U_{ijh'm}, \forall h \in H_{ij}, \forall h' \in H_{ij}, h \neq h', \forall ij \in \Omega_1, k \in \Omega_2 \tag{1}$$

where Ω_1 is the set of regional pairs.

The utility in each route assumingly consists of a deterministic term, V_{ijh}, irrespective of cargo m, and an unobservable term (in other words, error term), ε_{ijhm}, as shown in Equation (2):

$$U_{ijhm} = V_{ijh} + \epsilon_{ijhm} \tag{2}$$

The distributions of the error term, ε_{ijhm}, are assumed to be independent of each cargo m; in other words, random utility theory is adopted. If the distribution of the error term follows the Gumbel distribution, the choice probability, P_{ijh}, that the utility U_{ijhm} of route h is the largest among all possible routes, $U_{ijh'm}$, is described as Equation (3)

$$P_{ijh} = \exp(\theta \cdot V_{ijh}) \Big/ \sum_{h \in H_{ij}} \exp(\theta \cdot V_{ijh}) \tag{3}$$

where θ is the distribution parameter.

The deterministic term, V_{ijh}, is assumed to be the function of shipping cost and time, focusing on cost-effectiveness. To simplify the model, the freight charge for each shipping company is assumed to be unchangeable. Moreover, the deterministic term, as well as the utility function, is defined as per unit vessel capacity, assuming that vessel size is given by each voyage. Consequently, in this model, the deterministic term is defined as the following equation:

$$V_{ijh} = -(C_{ijh} + \alpha_1 \cdot TT_{ijh} + \alpha_2 \cdot Vage_{ijh}) \tag{4}$$

where C_{ijh} is the shipping costs per unit capacity (\$/ton) for route h from region i to region j; TT_{ijh} the time-related costs per unit capacity (\$/ton); $Vage_{ijh}$ the age for the vessel, and α_1, α_2 the weight parameters for each independent variable.

(2) Transit costs

The shipping costs per unit capacity (\$/ton), C_{ijh}, for each regional pair and route are defined as follows:

$$C_{ijh} = \frac{(TC_{ijh} + FC_{ijh}) \cdot T_{ijh} + CT_{ijh}}{Vcap_{ijh}} \tag{5}$$

where TC_{ijh} is the time charter of a vessel (\$/vessel/day); FC_{ijh} the fuel cost per unit capacity (\$/vessel/day); SCC_{ijh} the SC transit costs (\$/vessel); T_{ijh} the shipping time (days); and $Vcap_{ijh}$ the vessel size (DWT).

Time charter costs of a vessel per day, TC_{ijh}, refer to the payments made by the charterer to the vessel owner for using the vessel's services for a specified period of time. Time charter costs are subject to fluctuations and are contingent upon the demand for different vessel sizes and market conditions.

The fuel cost, FC_{ijh}, and fuel consumption rate of a vessel (ton/day), FR_{ijh}, are defined as Equations (6) and (7). The wave resistance experienced by a vessel during navigation is proportional to the square of the vessel's speed multiplied by the cross-sectional area under the water. Therefore, as noted by Shibasaki et al.[1], the fuel consumption rate in this study is assumed to be proportional to the product of the wave resistance and the ship's speed.

$$FC_{ijh} = BP \cdot FR_{ijh} \tag{6}$$

$$FR_{ijh} = a_1 \cdot Vcap_{ijh}^{\frac{2}{3}} \cdot v_{ijh}^3 \tag{7}$$

where BP is the bunker price (\$/ton); a_1 coefficient for fuel consumption defined by vessel type; and v_{ijh} the vessel speed of route h from region i to region j (knots).

The time-related costs per unit capacity, TT_{ijh}, is defined as

$$TT_{ijh} = \beta \cdot up_{ij} \cdot T_{ijh} \tag{8}$$

where β is the coefficient related to the cargo inventory (per day) equivalent to 10% of the annual interest rate; and up_{ij} the unit price (\$/ton).

The shipping time, T_{ijh}, for each regional pair and choice are defined as

$$T_{ijh} = (l_{ijh}/v_{ijh})/24 \quad (9)$$

where l_{ijh} is the shipping distance of route h from region i to region j (in nautical miles, or NM).

(3) Suez Canal toll

The SC toll, CT_{ijh}, for different vessel sizes and types is determined by the SCA, is defined as

$$CT_{ijh} = SDRrate \cdot b_1 \cdot scnrt_{ijh} \quad (10)$$

where *SDRrate* is the conversion rate from SDR (unit of account for the SC) to US dollars; $scnrt_{ijh}$ the net registered tonnage of a vessel for the SC, which is defined by vessel type; and b_1, the coefficients established by the SCA. The toll per vessel size decreases as vessel size increases.

The International Monetary Fund provides the annual average conversion rate from SDR to US dollars based on spot exchange rates. Although there are annual fluctuations, the changes in the conversion rate from 2013 to 2021 were not significant. Therefore, the average conversion rate of 1.43 was calculated and utilized for the analysis.

(4) Estimation of unknown parameters

Maximum likelihood estimation is a method that determines values for the parameters of a model. The parameter values are found such that they maximize the likelihood that the process described by the model produced the data that were actually observed. The unknown parameters – distribution parameter, θ, and weight parameters for time-related cost and vessel age, are estimated to agree with the actual choice results through a likelihood maximization method. Likelihood, L, is defined with the observed share of each route, P_{ijh}, and estimated share from the model, considering that the observed share acquired in the previous section focuses on the choice between the SC and the Cape route:

$$L = \prod_{i,j\in\Omega} (q_{ij} \cdot \hat{p}_{m,ij|h=SC})^{q_{ij} \cdot P_{m,ij|h=SC}} \cdot \prod_{i,j\in\Omega} (q_{ij} \cdot (\hat{p}_{m,ij|h=Cape})^{q_{ij} \cdot P_{m,ij|h=Cape}} \quad (10)$$

where q_{ij} is the observed vessel capacity (DWT/year) navigating from region i to region j. Unknown parameters are estimated to maximize L since this is maximized if the observed and estimated shares completely agree. Thus,

$$\max_{\theta,\alpha} lnL. \quad (11)$$

4. Modeling Results

The unknown parameters will be estimated by the maximum likelihood method based on the logit model. The estimated number of vessels transiting the SC will then be compared with the actual number of vessels.

The model will be deployed to perform three kinds of simulations that quantitatively evaluate the potential impacts of changes in market conditions, including variations in bunker price, time charter, and the SC tolls policies, on the SC transit share within the global maritime transport network. A decrease in bunker price and time charter is supposed to lead to a reduction in SC transit. This trend is attributed to the relative weight of canal tolls in the overall cost item increasing as bunker prices or time charters decrease and SC transit decreases. Furthermore, a reduction in the SC tolls led to a rise in SC transit. This shift is driven by the heightened economic appeal of the SC route due to lower tolls, enticing more shipping companies to opt for this route.

5. Conclusion

This study established a methodology for estimating both the route choice of product tankers and LNG carriers on a global scale, focusing on the share of SC transit navigation for regional pairs defined by cargo origin and destination. The Alphatanker vessel movement database, a subsidiary of AXS Marine that focuses on liquid bulk shipping data, was utilized to develop the database. A logit model was applied to predict the shares of each route by regional pair, reflecting the preferences of shipping companies and ship owners. Input data were drawn from several data sources and used in simulations reflecting possible changes in the tanker shipping market, such as the decline in bunker prices, the decline in time charter cost, and the reduction of the SC tolls policies.

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