International Core Journal of Engineering Volume 5 Issue 12, 2019
ISSN: 2414-1895 DOI: 10.6919/ICJE.201911_5(12).0025

Research on the problem of liner fleet deployment with the consideration of speed and volume change

Yuan Liu [1,*], Gang Zhao [1], Jiahui Ji [2], Sheng Song [1]

[1]College of Transport and Communications, Shanghai Maritime University, Shanghai, China

[2]KOREA MARITIME INSTITUTE, China Research Center, China

Corresponding author.

[a]liuyuan815280690@163.com(Yuan Liu)

Abstract

This paper considered the influence of speed on the change of cargo volume, and analyzes the relationship between speed and fuel consumption and voyage time. The total profit of the plan period is maximized by taking the speed and the number of ships and the number of idle ships as the decision variables. For the purpose, a mixed integer nonlinear model is constructed.

Keywords

Speed; cargo volume;fleet deployment; profit maximization.

1. Literature review

In order to obtain the maximum economic benefits, shipping companies often face the problem of properly arranging multiple ship types on multiple routes, namely the problem of fleet deployment. The research of this problem is often concentrated on the container liner transportation. Wang [1], through the research on the container liner transportation related literature, starts from the assumptions in the basic model of the liner fleet deployment, and considers the transshipment, the demand uncertainty, and the empty container transportation, speed optimization, summarized the existing container liner fleet deployment model , and the future research should further include demand under service impact, pollutant and emission, shipping alliance and so on. The research directions of the existing liner fleet deployment problem are mainly as follows:

1.1 Liner fleet deployment with uncertain demand

It is generally assumed that the container transportation demand is determined. In order to make the liner fleet deployment model more closer to reality, in recent years, the problem of liner fleet deployment under the condition of uncertain demand has been studied, mainly in terms of opportunity constraints and stochastic optimization. Wang [2] used the log normal distribution to describe the uncertainty of demand and established a liner fleet deployment model. Ng[3] describes the uncertainty of freight demand by means of mean, variance and upper bound, and establishes a liner fleet deployment model. Since then, Ng [4] has further relaxed the requirement that the mean and variance are known, increasing the random dependence of the freight demand between the ports. Ng[5] analyzed the liner fleet deployment model and found that the calculation of the number of voyages only calculated the complete number of voyage that could be completed during the planning period. However, the range of less than one complete voyage was directly ignored. There have a very obvious counterexample. If the voyage time exceeding the planned period ,so the ship will not be arranged to operate .Based on this, Ng improved the model, increased the incomplete voyage, and changed the number of complete voyages of one decision variable to the number of port of calls. The numerical

ISSN: 2414-1895 DOI: 10.6919/ICJE.201911_5(12).0025

case show that the new model can reduce the cost. Zhen [6] considered the influence of the uncertainty of container cargo weight on the ship's load during the long planning period, added the opportunity constraint in the model, and considered the transshipment, constructed a nonlinear model, and linearized the model and finally use the cplex to solve the model.

1.2 Considering empty container transportation and inventory management

On the issue of empty container transportation, Wang [7] added empty container constraints based on the O-D pair liner fleet deployment model and considered the re-arrangement of the ship. Huang [8] proposed a mixed integer linear programming model. The model contains several related constraints, such as the frequency of ship, the transshipment of goods between two or more service routes, and the transit time constraint. And used cplex to verify that the model can reduce the ship's capacity consumption and improve the ship's capacity utilization. Rahime [9] uses the age of the ship, the type of ship and the number of ships as the path cost, and builds the model framework based on the Benders formula. The route network design and empty container transportation are considered in the liner fleet deployment model. Saurabh [10] applied the liner fleet deployment model to the ro-ro ship transportation, and considered the inventory management of the cargo into the fleet deployment model, and proposed the RHH (rolling horizon heuristic) algorithm to solve the problem of short-term planning period.

1.3 Considering the pollution and emission

Zhu [11] considered the impact of the open Maritime Emissions Trading System (METS) on shipping companies and verified that METS can motivate operators to use new technologies, deploy more energy-efficient ships, and even build more energy-efficient ships. And when the fuel price is high, the effect is more obvious. Gu [12] demonstrated the role of METS (maritime Emission Trading Scheme) in the field of shipping. By constructing a capacity chartering and fleet deployment model, the results show that in the short term, the implementation of METS will not lead to emission reduction in most cases. However, in the case of low fuel prices, high quota costs or global METS coverage, a greater reduction in CO_2 emissions can be expected in the short term.

1.4 Fleet deployment combined ship route design

Shahin [13] uses the Lagrangian decomposition method as a tool to solve the difficulty of solving the MIP problem in a short time, and the results show how it can help to make better use of ships and reduce the use of fuel, thus providing more environmentally friendly service. Rodrigo [14] represented the route as a node of a directed graph for building a mixed integer programming model. The route with one or more empty sections is also used as a node of the directed graph to maximize profit by assigning ships and empty sections, route selection and schedule design. Wang [15] proposed a two-stage stochastic programming model by considering the lease time in time chartering and the number of chartered and leased ships in the fleet deployment model, and adding speed optimization and market uncertainty. Take Odfjell's data as a case. The results show that the leasing behavior can affect the operation of the shipping company, and the results of the model show the difference in the impact of leasing on the shipping company. Henrik [16] uses speed as a decision variable, and takes a roll-on ship transport as an example, designed a rolling horizon heuristic algorithm. It is proved by the case that the algorithm can solve the problem in a reasonable time. Ayşe N.Arslan [17] applied multi-stage stochastic programming to bulk cargo transportation, and used the time of chartering as a decision variable, and used demand and lease cost as uncertain variables to establish a model. And solved the problem by rolling horizon fashion. Song [18] built a dual-objective model with the goal of minimizing the cost of operating and fleet waste, and solved it by genetic algorithm. Meng [19] added the limitations of transshipment and transportation time in the model, and the container freight demand changed every week. An effective global optimization algorithm was proposed to carry out numerical experiments on the transportation data of the global liner shipping company. The applicability of the proposed model and algorithm is proved.

ISSN: 2414-1895 DOI: 10.6919/ICJE.201911_5(12).0025

2. Description of the problem

The problem of how to assign the existing shipping capacity to each route is studied by the liner company. In the issue of liner shipping, the route is known, the ship needs to visit each port on the route during the planning period, and the liner company usually needs to meet certain shipping interval in order to maintain certain market competitiveness. A voyage is issued for one week, that is, every other week. The goal is to maximize profits during the planning period.

The competition strategy of the liner company is often reflected in the schedule. The information that a schedule can reflect is: the number of voyages and the time of departure, the time of each voyage to visit each ports on the route, etc. The schedule is the shipping company's business card ,it is the main tool for the liner company to compete. Usually the shipper is concerned with the number of voyages and the time of arrival each ports. For shipping companies that meet the requirements of the shipper, the shipping service of the liner company is more likely to be purchased and used by the shipper. Therefore, the quantity of goods that the liner company can contract depends mainly on the possibility of the products or services produced by the shipping company being purchased by the owner.

In the liner fleet deployment model, it is usually that one vessel has to complete one or more voyages during the planning period to meet the capacity requirements on the route. In the past studies, the demand on the route is usually thought as a constant number. In some articles, the demand is set to a random variable (Wang[3], Ng[4], Ng[5]). According to the previous statistics, the distribution function of the demand is obtained, and the fleet deployment model is constructed by the random programming method. Moreover, the previous literature only considered the total cost to be the smallest, mainly because the total revenue is usually assumed to be constant, but the benefits of the liner company are related to the quantity and quality of services that can be provided. At the same time, the quantity of cargo that the liner company can undertake is also related to the quality of service provided by the liner company, that is, the length of transportation time. Since the voyage time of a complete voyage is equal to the voyage time plus the loading and unloading time and the time of entering and leaving the port, the time of entering and leaving the port can be obtained from the previous data and can be considered as a constant number related to the route. The loading and unloading time is mainly related to the size of the ship and the volume of cargo. When the same type of ship is sailing on the same route, the loading and unloading time is negligible compared to the sailing time, and the maximum impact on the voyage time is the sailing time. Therefore, it can be considered that the cargo volume is also related to the sailing time, that is, related to the speed.

There is a liner company that has operates R routes, sorting each route by 1, 2, 3...r...R. The company has a fleet of H types of ships, sorting the ship types, respectively 1, 2, 3, ... h, ... H, the capacity of each ship type is$\mathrm{q}_1, \mathrm{q}_2, \mathrm{q}_3,\ldots,\mathrm{q}_\mathrm{h},\ldots\mathrm{q}_\mathrm{H}$.The maximum number available of each ship type during the planning period (unit: ship/day) is $\mathrm{S}_1, \mathrm{S}_2, \mathrm{S}_3 ,\ldots, \mathrm{S}_\mathrm{h} ,\ldots \mathrm{S}_\mathrm{H}$ .the fixed cost (unit: ship/million) corresponding to each ship type are$C_1^{fix}, C_2^{fix}, C_3^{fix},\ldots,C_\mathrm{h}^{fix},\ldots C_\mathrm{H}^{fix}$.The length of the planned period is known as T and the ship's interval is known to be 7 days. The quantity of cargo picked up by the shipping company on a voyage is related to the ship type and sailing time. As the volume of the goods changes, the shipping company needs to deploy the appropriate ship type and speed on the appropriate route to get maximize profits.

This article also makes the following assumptions:

During the planning period, the port of the ship and its order are known;

During the planning period, the shipping company does not consider chartering and constructing new ships;

During the planning period, the freight rate on the route is known;

The transport capacity of ships transported between ports is measured by the number of containers;

ISSN: 2414-1895 DOI: 10.6919/ICJE.201911_5(12).0025

Assume that the upper and lower limits of the speed that can be obtained by all types of ships are the same;

1. Model construction

parameter settings:

R:｛1, 2, …, r, …I｝, the set of all ship routes

H:｛1, 2, …, h, …J｝, the set of all types of ship

O_r: the freight of r route（unit: dollar/container）

P: the price of oil（unit: dollar/ton）

N_h: the maximum available number for each h type ship during the planning period（unit: ship）

q_h: h type ship's capacity（unit: TEU）

S_h: The maximum available time for each h type ship during the planning period（unit: ship/day）

F_h: the idle cost of h type ship（unit: dollar/ship）

k_h:the fuel functional coefficient of h type ship

C_h^{fix}:the fix cost of h type ship(unit:dollar/ship)

t_{hr}:The mooring time of the h-boat on the r route(unit:day)

w_{hr}:The average loading rate of the h type ship on the r route under the influence of the speed is not considered.

V_{max}:the upper bond of ship speed(unit:knot)

V_{min}:the lower bond of ship speed(unit:knot)

Ø: Fractions greater than 0 and less than 1

Decision variables:

V_{hr}: The operational speed of the h type ship on the r route when considering the influence of the speed on the cargo volume during the planning period;

V_{hr1}: During the planning period, the optimum speed of the h type ship on the r route when not consider the speed affects the cargo volume.;

y_{hr}: The number of h type ships deployed on the r route during the planning period;

z_h: Number of idle h type ships in the plan period。

Consider the speed-affected the cargo volume,the liner fleet deployment model is below :

Total profit of liner company = total revenue - total cost.

Total revenue = sum of all route revenues.

The revenue of the r route = the freight rate of the r route* (the total cargo volume that is collected during the planning period when a certain type of ship is determined to sail at a certain speed).

The total volume of cargo received is related to the speed and ship type. When the influence of the speed is not considered, the amount of cargo received is equal to the amount of input ship capacity * average loading rate. When considering the influence of the speed of the ship, when sailing at a higher speed, it can attract more cargo, that is, increase the average loading rate of the ship. When the speed's influence is not considered, the optimal speed on the route isV_{hr1},the optimal speed which consider the influence of speed is V_{hr}.The time difference between the two speeds is $\frac{L_r}{V_{hr1}}—\frac{L_r}{V_{hr}}$ at this time, the ship loading rate = $w_{hr}+(\frac{\frac{L_r}{V_{hr1}}-\frac{L_r}{V_{hr}}}{24*T})Ø$, that is, the product of the ratio Ø and the shortening time is added to the original loading rate. When the ship is sailing on the route, the number of voyages that

ISSN: 2414-1895
DOI: 10.6919/ICJE.201911_5(12).0025

each h type boat can complete on the r route during the planning period is $\frac{S_h}{\frac{2L_r}{24V_{hr}}+t_{hr}}$, so the total revenue on all routes is equal to

$$\sum_{h\in H}\sum_{r\in R} O_r y_{hr}\, q_h(w_{hr} + (\frac{\frac{L_r}{V_{hr1}} - \frac{L_r}{V_{hr}}}{24 * T})Ø)\frac{S_h}{\frac{2L_r}{24V_{hr}} + t_{hr}}$$

The total cost is analyzed below:

Total cost = sum of all route cost.

Cost of the r route = fuel cost of the shipping company on the r route + fixed cost + idle cost.

The fuel cost is mainly related to the number of voyages and the speed of each voyage. When the speed of the h type ship on the r route is V_{hr}, the fuel consumption of a round-trip voyage is $\frac{2L_r}{24V_{hr}} * k_h(V_{hr})^3$. Therefore, the fuel consumption on all routes during the planning period is $\sum_{h\in H}\sum_{r\in R}\frac{2L_r}{24V_{hr}}k_h(V_{hr})^3\frac{S_h}{\frac{2L_r}{24V_{hr}}+t_{hr}}y_{hr}$.

The fixed cost is related to the ship type and the number of ships to be assigned. The fixed cost of the fleet during the planning period is equal to the sum of the fixed costs of the number of ships on all routes on all ships, so the fixed cost $\sum_{h\in H}\sum_{r\in R} y_{hr} * C_h^{fix}$.

Idle cost = number of idle ships * idle cost of the ship type=$\sum_{h\in H} z_h * F_h$.

The following constraints are analyzed:

For h type ship, the number of ships operated plus the number of idle ships is equal to the maximum number of h type ship available, $\sum_{r\in R} y_{hr}+z_h=N_h, \forall h \in H$.

The round trip time is equal to the ship's interval multiplied by the number of ships assigned, $7J\sum_{h\in H} y_{hr} = \sum_{h\in H}\frac{2L_r}{24V_{hr}} + t_{hr}, \forall r \in R$, J is the total number of all ship type.

The operating speed is between the upper and lower speed limit, $V_{min} \le V_{hr} \le V_{max}$.

So the model is as follows:

$$\text{Max}= \sum_{h\in H}\sum_{r\in R} O_r y_{hr}\, q_h(w_{hr} + (\frac{\frac{L_r}{V_{hr1}} - \frac{L_r}{V_{hr}}}{24*T})Ø)\frac{S_h}{\frac{2L_r}{24V_{hr}}+t_{hr}} - \sum_{h\in H}\sum_{r\in R}\frac{2L_r}{24V_{hr}}k_h(V_{hr})^3\frac{S_h}{\frac{2L_r}{24V_{hr}}+t_{hr}}y_{hr}\,P - \sum_{h\in H}\sum_{r\in R} y_{hr}\, C_h^{fix} - \sum_{h\in H} x_h F_h \quad (1)$$

$$\sum_{r\in R} y_{hr}+z_h=N_h, \forall h \in H \quad (2)$$

$$7J\sum_{h\in H} y_{hr} = \sum_{h\in H}\frac{2L_r}{24V_{hr}} + t_{hr}, \forall r \in R \quad (3)$$

$$V_{min} \le V_{hr} \le V_{max} \quad (4)$$

$$y_{hr}, z_h \text{ as integer} \quad (5)$$

represents profit maximization, (2) represents ship quantity constraint, (3) represents the relationship between the number of ships and speed, and (4) (5) represents the the constraint of the range of values of decision variable.

3. Conclusion

In this paper, the model of liner shipping model under the influence of speed on cargo volume is studied. A mixed integer nonlinear model is constructed with the speed, the number of ships and the number of idle ships as decision variables. In the current market conditions, considering the speed into the liner fleet deployment model has certain significance for the operation of the liner company.

ISSN: 2414-1895 DOI: 10.6919/ICJE.201911_5(12).0025

References

[1]ShuaianWang,Qiang Meng. Container liner fleet deployment: A systematic overview[J]. Transportation Research Part C,2017,77.

[2]TingsongWang,QiangMeng,ShuaianWang,Zhijia Tan. Risk management in liner ship fleet deployment: A joint chance constrained programming model[J]. Transportation Research Part E,2013,60.

[3]ManWo Ng. Distribution-free vessel deployment for liner shipping[J]. European Journal of Operational Research,2014,238(3).

[4]ManWo Ng. Container vessel fleet deployment for liner shipping with stochastic dependencies in shipping demand[J]. Transportation Research Part B,2015,74.

[5]ManWo Ng. Revisiting a class of liner fleet deployment models[J]. European Journal of Operational Research,2017,257(3).

[6]Lu Zhen,Yi Hu,Shuaian Wang,Gilbert Laporte,Yiwei Wu. Fleet deployment and demand fulfillment for container shipping liners[J]. Transportation Research Part B,2019,120.

[7]Shuaian Wang. Essential elements in tactical planning models for container liner shipping[J]. Transportation Research Part B,2013,54.

[8]You-Fang Huang,Jian-KunHu,Bin Yang. Liner services network design and fleet deployment with empty container repositioning[J]. Computers & Industrial Engineering,2015,89.

[9]Rahime Neamatian Monemi,Shahin Gelareh. Network design, fleet deployment and empty repositioning in liner shipping[J]. Transportation Research Part E,2017,108.

[10]Saurabh Chandra,Marielle Christiansen,Kjetil Fagerholt. Combined fleet deployment and inventory management in roll-on/roll-off shipping[J]. Transportation Research Part E,2016,92.

[11]MoZhu,Kum Fai Yuen,Jia Wei Ge,Kevin X. Li. Impact of maritime emissions trading system on fleet deployment and mitigation of CO 2 emission[J]. Transportation Research Part D,2018,62.

[12]Yewen Gu,Stein W. Wallace,Xin Wang. Can an Emission Trading Scheme really reduce CO 2 emissions in the short term? Evidence from a maritime fleet composition and deployment model[J]. Transportation Research Part D,2019,74.

[13]Shahin Gelareh,Nelson Maculan,Philippe Mahey,Rahimeh Neamatian Monemi. Hub-and-spoke network design and fleet deployment for string planning of liner shipping[J]. Applied Mathematical Modelling, 2013,37(5).

[14]Rodrigo Moretti Branchini,Vinícius Amaral Armentano,Reinaldo Morabito. Routing and fleet deployment in liner shipping with spot voyages[J]. Transportation Research Part C,2015,57.

[15]Xin Wang,Kjetil Fagerholt,Stein W. Wallace. Planning for charters: A stochastic maritime fleet composition and deployment problem[J]. Omega,2018,79.

[16]Henrik Andersson,Kjetil Fagerholt,Kirsti Hobbesland. Integrated maritime fleet deployment and speed optimization: Case study from RoRo shipping[J]. Computers and Operations Research,2015,55.

[17]Ayşe N. Arslan,Dimitri J. Papageorgiou. Bulk ship fleet renewal and deployment under uncertainty: A multi-stage stochastic programming approach[J]. Transportation Research Part E,2017,97.

[18]Yajie Song,Yixiang Yue. Optimization Model of Fleet Deployment Plan of Liners[J]. Procedia Engineering,2016,137.

[19]Qiang Meng,Shuaian Wang. Liner ship fleet deployment with week-dependent container shipment demand[J]. European Journal of Operational Research,2012,222(2).