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Optimization of Shipping Line Deployment Based on EXCEL and Mixed Integer Programming Model

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Abstract

Fleet deployment is a complicated decision problem that must be faced by both the owner and charterer, especially in liner transportation. Therefore, an LNG fleet allocation problem studied by predecessors was optimized. In the shipping cost, the fuel cost accounts for a large proportion, and the shipping route speed is the main factor to determine the fuel consumption. Therefore, in the future, the problem of route allocation will be further optimized to make it more practical. By introducing the parameter of speed, the mixed integer programming model will be optimized by combining the changes of various costs of ships under different speeds, namely the relevant parameters, and the nonlinear programming solution method of Excel will be used for analysis. The results show that the annual operating cost can be reduced when ships with different speeds are arranged to replace fleets on different routes or on the same route and put into the operation of ships with the same speed..

Keywords

Fleet deployment; Optimizing decision-making; Mixed integer programming; Liner shipping.

1. Introduction

At present, both economic development and environmental protection have become the theme of world development. Although there is a certain contradiction between economic development and environmental protection, with the emergence of clean energy such as natural gas, this contradiction is expected to be further alleviated in the future. The natural gas transaction in reality is completed through LNG shipping. Many countries in the world are establishing acceptance stations, and large oil companies in the international scope also begin to attach importance to LNG transportation business. The continuous launching of LNG shipping in China also proves the continuous growth of LNG business. For LNG carriers, it is a problem that they have to face to decide how to allocate ships to maximize the lowest cost and profit. Shipping line allocation is the central part of LNG shipping company's production plan, and it is a complex optimization decision work to design the operation problem of multi-type ships and multiple routes of shipping companies.

Many research papers have been published both at home and abroad on the issue of ship routing, and various model algorithms have been proposed [1-3]. But for different companies, different types of ships, different routes and different navigation areas of the ship with different emphasis on the problem is different. This paper optimizes the model based on the previous paper, adding the parameter K, namely the ship speed, to make it more in line with the reality and further optimize the shipping line matching model [4].Because fuel cost accounts for a large proportion in ship transportation cost, and ship route speed is the main factor determining fuel consumption, and fuel

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consumption is proportional to the cubic square of ship speed [5-6].Arrange ships at different speeds to save fuel consumption and minimize costs.

2. Built a deployment model

2.1 Question assumptions

In the actual operation, on the premise of meeting the annual freight demand of all routes and the minimum shipping frequency, each shipping company hopes to organize the best shipping scheme with the minimum annual operating cost. Due to the incomplete consistency between theory and reality, the following assumptions were considered in the subsequent model establishment and calculation:

1) The ship carries LNG cargo with full load on the return journey

2) The fleet has I types of ships and J routes, and each type has K different rated speeds.

3) The freight volume of each route shall be determined with the fluctuation ratio of A and the freight rate shall remain unchanged.

4) The same operating expenses, loading and unloading capacity and efficiency are incurred by the same type of ships when loading and unloading the same cargo.

5) Sufficient supply, regardless of the cost of idle goods.

This paper is devoted to studying the variation of fleet operating cost at different speeds. Based on previous studies, this paper introduces the variation parameter of speed to compare the difference between the new optimization model and the previous model.

2.2 mathematical model

Taking the lowest operating cost of fleet as the objective function, the mathematical programming model of this problem is established as follows.

Objective function:

$$\text{Min } Z = \sum_{k=1}^{K} \sum_{i=1}^{I} \sum_{j=1}^{J} C_{ijk}\, x_{ijk} \tag{1}$$

constraint function:

$$\sum_{k=1}^{k} \sum_{i=1}^{I} x_{ijk} V_{ijk} \geq (1-a) W_j \qquad j = 1,2,3 \ldots J \tag{2}$$

$$\sum_{k=1}^{k} \sum_{i=1}^{I} x_{ijk} V_{ijk} \leq (1+a) W_j \qquad j = 1,2,3 \ldots J \tag{3}$$

$$\sum_{i=1}^{I} \sum_{k=1}^{K} x_{ijk} \geq M_j \qquad j = 1,2,3 \ldots J \tag{4}$$

$$x_{ijk} t_{ijk} = T_{ik} N_{ijk} \qquad i = 1,2,3 \ldots I;\ j = 1,2,3 \ldots J \tag{5}$$

$$\sum_{k=1}^{K} \sum_{j=1}^{J} N_{ijk} = N_i^{max} \qquad i = 1,2,3 \ldots I \tag{6}$$

$$x_{ij}, N_{ij} \geq 0 \tag{7}$$

Where, Z is the objective function, the annual operating cost of fleet; x_{ijk} is the decision variable, and the number of annual voyages of type i ship on route j at the speed of k; N_{ijk} is an integer variable, which is assigned to the number of Type i ships on route j with speed k; C_{ijk} is the operation cost of type i ship at the speed of k on route j; V_{ijk} refers to the number of trips carried by type i ship at the speed of k on route j; W_j is the annual freight volume that should be completed on route j; M_j is the minimum planned frequency on route j; t_{ijk} is the voyage time of type i ship at the speed of k on route j; T_{ik} is the annual trial days of type i ship with a speed of k; N_i^{max} is the number of Type i ships available; I is the total number of ship types;J is the total number of routes.

There into,

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$$C_{ijk}=\frac{d_j}{24v_{ik}}\left(f_{ik}p^f+g_{ik}^p p^g\right)+t_{ijk}^p g_{ik}^p p^g+t_{ijk}G_{ik}+O_{ijk} \tag{8}$$

In formula (8), d_j is the distance of route j; v_{ik} is the speed of ship type i; f_{ik} is the fuel consumption per day of the type i ship at the speed of K; p^f is the fuel price of the propulsion engine; g_{ik}^p is the fuel consumption of the generator per day of the type i vessel at the speed of k; p^g is Fuel price for generators; t_{ijk}^p is the berthing time of the voyage at the speed k on the course j; G_{ik} is the daily fixed cost of sailing at speed k; O_{ijk} refers to other voyage expenses of type i ship with speed k on route j;

The formula (8) can be simplified into three parts, that is,

$$C_{ijk}=F_{ijk}+I_{ijk}+O_{ijk} \tag{9}$$

In the formula, F_{ijk} is the fuel consumption cost of the voyage of type i ship on route j at the speed of k; I_{ijk} refers to the fixed cost of the voyage of type i ship at the speed of k on route j.

When different speed K is introduced, it is assumed that the conditions such as single load of the ship are unchanged, which will lead to changes in voyage time, ship fuel cost, voyage cost and operating cost, etc. For the convenience of calculation, the newly added parameter speed K is incorporated into the ship type column, so that the difference from the previous one is the increase of the ship type and the corresponding change of various costs. The function (1) - (9) is simplified as follows

$$\text{Min } Z=\sum_{i=1}^{I}\sum_{j=1}^{J}C_{ij}\,x_{ij} \tag{1'}$$

$$\sum_{i=1}^{I}\sum_{j=1}^{J}C_{ij}\,V_{ij}\geq(1-a)W_j \qquad j=1,2,3\ldots J \tag{2'}$$

$$\sum_{i=1}^{I}x_{ij}\,V_{ij}\leq(1+a)W_j \qquad j=1,2,3\ldots J \tag{3'}$$

$$\sum_{i=1}^{I}x_{ij}\geq M_j \qquad j=1,2,3\ldots J \tag{4'}$$

$$x_{ij}t_{ij}=T_iN_{ij} \qquad i=1,2,3\ldots I;\ j=1,2,3\ldots J \tag{5'}$$

$$x_{ij}=N_i^{max} \qquad i=1,2,3\ldots I \tag{6'}$$

$$x_{ij},N_{ij}\geq 0 \tag{7'}$$

$$C_{ij}=\frac{d_j}{24v_i}\left(f_ip^f+g_i^p p^g\right)+t_{ij}^p g_i^p p^g+t_{ij}G_i+O_{ij} \tag{8'}$$

$$C_{ij}=F_{ij}+I_{ij}+O_{ij} \tag{9'}$$

3. Case study

Table 1. Basic information of each ship type

Ship type	Available quantity/ship	capacity/10^4m^3	Voyage cargo capacity /10^4m^3	Speed (knots)	Annual operating time /d
1	1	14.7	13.2	19.5	345
2	2	14.7	13.2	17.5	345
3	1	16	14.4	19.5	345
4	1	16	14.4	17.5	345
5	1	22	19.8	19.5	345
6	1	22	19.8	17.5	345

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In order to further exemplify the model, the relevant data in the original model were used for calculation and comparison. In order to illustrate the feasibility of the optimization scheme, the new cost variation values at different speeds were added to satisfy the computability. Relevant data are shown below, see Table 1-4. As can be seen from the table, increasing the speed of each original ship type doubles the number of original ships.

Table 2. Basic information of all routes

route	distance/mile	Annual demand/10^4m^3	Fluctuation in proportion	Minimum number of sailings
1	4400	700	5%	40
2	6300	680	5%	38

Table 3. Sailing schedules of each ship type on each route

Ship type	time for sailing /d	time-in-port /d	Trip time /d
1	18.8|27	3.2|3.2	22|30.2
2	20.9|30	3.2|3.2	24.1|33.2
3	18.8|27	3.3|3.3	22.1|30.3
4	20.9|30	3.3|3.3	24.2|33.3
5	18.8|27	4.1|4.1	22.9|31.1
6	20.9|30	4.1|4.1	25|34.1

Note: the data to left of "|" is the time on route 1, and the right data is the time on route 2

Table 4. Operating costs of each ship type on each route

Ship type	Voyage fuel charge / (Thousands dollars)	Fixed voyage cost/million dollars	Other voyage costs /Thousands dollars	Voyage operating cost /million dollars
1	33.38|47	1.69|2.46	12.5|13.64	2.15|3.07
2	30.47|45.67	1.70|2.48	12.5|13.64	2.13|3.07
3	35.13|49.45	1.87|2.72	13.13|16.36	2.35|3.38
4	32.47|46.35	1.88|2.73	13.13|16.36	2.34|3.36
5	45.38|63.82	2.14|3.11	15.63|18.18	2.75|3.93
6	42.54|60.98	2.15|3.12	15.63|18.18	2.73|3.91

Note: the data to left of "|" is the cost on route 1, and the right data is the cost on route 2

With the introduction of new speed value, the corresponding trip time and operating costs will change accordingly, according to the speed reduce voyage time increases, the change of voyage cost reduction, in order to be able to make the mathematical model can be calculated, the form of the new speed voyage time, operating costs are proportional default, in the actual operation, according to the parameters of the ship under different speed corresponding input can get the actual real optimization scheme, the same way, in the play the role of comparative reference only experience.

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4. Model solution and analysis

Excel programming was used to solve the problem. Input the above parameters into the Excel table, and complete the planning parameters and functions according to the mathematical model, mainly including the objective function, variable parameters, constraint function, etc. After the solution, the possible optimal route shipping scheme for the company considering ships at different speeds is obtained, see Table 5.

Table 5. Optimal route allocation scheme table

Ship type	Deployed Ships on the route	
	route1	route2
1	0	1
2	0	2
3	0	1
4	1	0
5	1	0
6	0	1

=SUMPRODUCT(G4:H9,I15:J20)

D	E	F	G	H	I	J	K	L	M	N
	available number		voyage cost		Voyage production capacity		voyage time			
			route1	route2	route1	route2	route1	route2	service time/day	
	1	type1	2.15	3.07	13.2	13.2	22	30.2	345	345
	2	type2	2.13	3.07	13.2	13.2	24.1	33.2	345	345
	1	type3	2.35	3.38	14.4	14.4	22.1	30.3	345	345
	1	type4	2.34	3.36	14.4	14.4	24.2	33.3	345	345
	1	type5	2.75	3.93	19.8	19.8	22.9	31.1	345	345
	1	type6	2.73	3.91	19.8	19.8	25	34.1	345	345
				demand/route/year	700	680				
				(1-5%)W	665	646				
				(1+5%)W	735	714				
		available nu	Vessel number		number of voyage					
		1	0	1	0	8				
		2	0	2	0	0				
		1	0	1	0	3				
		1	1	0	1	0			xij*tij	2242.3
		1	1	0	33	3			ti*nij	2415
		1	0	1	6	26				
					40	38				
					40	40				
					objective function	257.62				
				x_ij v_ij	667.8	663.6				

Figure 1. Excel nonlinear solution process and results

Figure 1 shows the excel solution process. The yellow and blue areas are variable parameters, namely, the solution.

As shown in Figure 1, under the condition that the number of ships remains unchanged and the minimum voyage frequency is met and the new speed is added, all ships are put into use. Route 1 actually completed the annual freight volume $667.8 * 10^4 m^3$; Route 2 actually completed the freight volume $663.6 * 10^4 m^3$, both meeting the annual shipping demand. Under the new ship allocation scheme, the annual operating cost and objective function value of the entire fleet reach a minimum of 257.62 million US dollars, which is less than the cost of 263.90 million US dollars for the entire fleet using the same speed. This shows that according to the cost values of different ships at different speeds and on different routes of the company, the number of ships can be reasonably arranged in a

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scientific way, so as to reduce the operating cost on the premise of achieving the annual shipping target.

5. Conclusion

For liner transport or large long route scheduled tanker transport, the objective function with the lowest annual operating cost can be established to optimize the shipping route allocation model. In this paper, by changing the parameters at different speeds, the annual operating cost can be reduced by making the fleet rationally arrange shipping routes according to the actual ship size. According to this method, different companies can optimize shipping routes according to their own fleet conditions. The problem is cost minimization.

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