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# Optimization of liner route allocation considering carbon emissions

*Yongcen* Shen[1,*]

[1]Transportation, Shanghai Maritime University, Shanghai, 201306, China.

**Abstract.** With the general awareness of energy and environmental issues in the whole society, the issue of greenhouse gas emission reduction has gradually become the focus of attention. Ocean transport undertakes more than 90% of the world's cargo transportation and also produces a large amount of carbon dioxide. In order to achieve carbon emission reduction in the shipping industry, in June 2012,the ECOFIN proposed to impose a Maritime Carbon Tax, which will increase the operating costs of shipping companies. In view of this, it is of great significance to consider carbon emission factors in the optimization of liner routes. This paper considers the carbon emissions of maritime transportation, establishes a mathematical model that minimizes operating costs such as maritime carbon tax, ship management fees, and fuel costs, verifies the effectiveness of the algorithm through calculation examples, and provides a plan for the carrier to make optimization decisions on liner route allocation.

## 1 Introduction

In recent years, the global transportation industry has developed vigorously, along with rising carbon dioxide emissions, which has brought tremendous pressure to the environment[1].

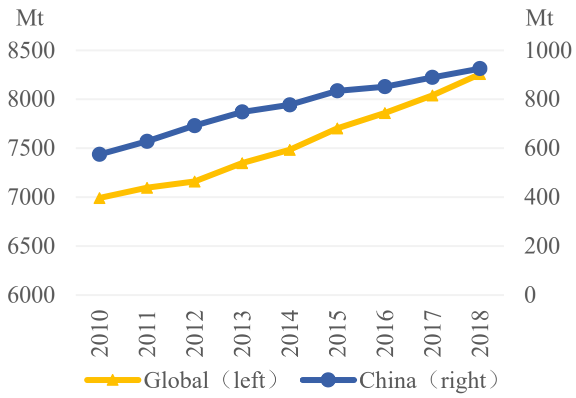


**Fig. 1.** $CO_2$emissions by transport in the world and China from 2010 to 2018

As one of the important modes of transportation, seaborne $CO_2$emissions have also been increasing in recent years[2].

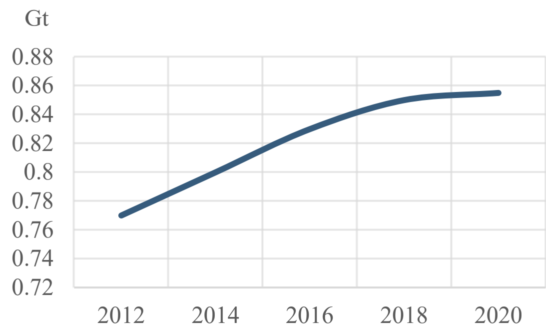


**Fig. 2.**CO2 emissions from the shipping industry 2012-2020

According to data from the International Maritime Organization (IMO), in 2020, there will be about 90,000 seaborne ships in the world, consuming about 350 million metric tons of fuel, and $CO_2$emissions as high as 1.4 billion tons[3]. In order to achieve carbon emission reduction in the shipping industry, the IMO passed two mandatory performance and efficiency standards related to carbon emission reduction of all ships for the first time at the 2011 meeting[4]. In 2018, IMO planned to reduce carbon dioxide emissions from international shipping by more than half of 2008 emissions by 2050, and carbon emission reduction targets for 2030 and 2050 were set. The levy of the *Maritime Carbon Tax* was proposed at the ECOFIN in June 2012[5], and the corresponding price list was also born. In 2013, with the emergence of the *Maritime Carbon Emission Regulation Draft*, the *Maritime Carbon Tax* was legislated[6].

*Yongcen Shen: 202030610168@stu.shmtu.edu.cn

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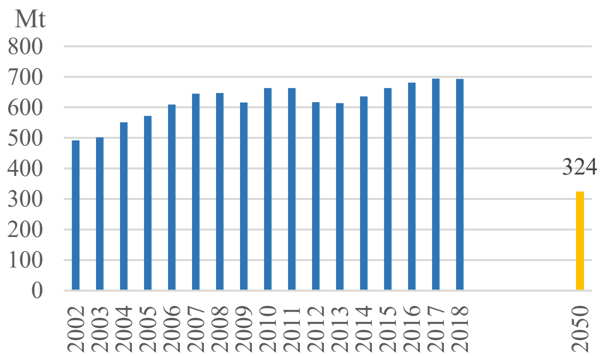


**Fig.3.** $CO_2$emissions from international shipping 2002-2018 and under the sustainable development scenario 2050
**Source.** International Energy Agency, IEA

According to data from relevant scholars, if we take the CO2 emissions of Chinese shipping industry as a benchmark in 2009, and over 85% of the benchmark is taxed and calculated at US$25 per ton of carbon dioxide, Chinese maritime carbon tax should be paid for US$237 million in 2014. If no measures are taken, this additional cost will put tremendous pressure on shipping companies. At present, when liner companies weigh the relationship between revenue and environment, they usually adopt strategic, tactical and operational decisions[7].Since strategic decisions will not change easily, flexibility in tactical and operational decisions is particularly important.

## 2 Problem description and model construction

In a stable planning period, given the number of containers required between a series of departure ports and destination ports, the minimum annual operating cost of the liner company's fleet is taken as the goal to determine the number of ships deployed on each route.So, the objective functions as follows.

$$\text{MinZ} = \sum_{j=1}^{n}\sum_{h=1}^{n} X_{\text{jh}} \cdot R_{jh} + \sum_{j=1}^{n} O_j \cdot F_j \tag{1}$$

Among them, $R_{jh}$ = crew's annual salary of single ship + insurance premium of single ship + annual repair fee of single ship + annual fuel cost of single ship + annual refuelling fee of single ship + annual material cost of single ship + annual port commission of single ship + annual management fee of single ship + annual maritime carbon tax of single ship.

Subject to:

$$\sum_{j=1}^{n} X_{jh} \cdot V_{jh} = W_h (j \in N, h \in N) \tag{2}$$

$$\sum_{h=1}^{n} X_{jh} + O_j = A_j (j \in N, h \in N) \tag{3}$$

$$\sum_{h=1}^{n} X_{jh} + O_j = A_j (j \in N, h \in N) \tag{4}$$

**Table 1.** The meaning of each parameter

| Parameter | Meaning |
|---|---|
| $Z$ | Annual operating cost of the shipping company |
| $X_{jh}$ | The number of j-type ships on the h route |
| $O_j$ | Number of idle j-type ships |
| $R_{jh}$ | The annual operating cost of a single ship of the j-type ship on the h route |
| $F_j$ | Annual cost of idle j-type ship |
| $V_{jh}$ | Annual capacity of a single ship on route h of type j |
| $W_h$ | The annual transportation volume required by h route |
| $A_j$ | Number of j-type ships in the fleet |

## 3 Model application

Below we use the above model, from the perspective of shipping companies, with the goal of minimum operating costs in 2019, to optimize the number of ships allocated to current China-Europe routes of COSCO SHIPPING. (The outbreak of the COVID-19 began in January 2020, and the international liner shipping industry fluctuates throughout the year, so 2019 is selected as the research object.)

Four typical container ship types operating on the China-Europe route are selected.The number and main parameters of each type of ship as follows.Firstly, There are 5 19100TEU ships represented by the *CSCL PACIFIC OCEAN*, with a net tonnage of 187,000 tons, a ship cost of US$130 million, a speed of 25 knots, a daily consumption is 494 tons of fuel, 2 tons of diesel fuel while sailing and 4 tons of fuel while berthing. It has 20 crew members.Secondly, There are eight 14100TEU ships represented by the *CSCL MERCURY*, with a net tonnage of 155,374 tons. The cost of the ship is US$117 million, and the speed is 24 knots. A daily consumption is 399 tons of fuel, 2 tons of diesel fuel while sailing and 4 tons of fuel while berthing. There are 20 crew members. Thirdly, There are four ships of 20119TEU represented by the *COSCO SHIPPING Gemini*, with a net tonnage of 202,000 tons. The cost of the ship is US$210 million, with a speed of 22.5 knots, consumes 532 tons of fuel per day when sailing, 2 tons of diesel per day when sailing, and 5 tons of fuel per day when berthing, with 22 crew members. Lastly, There are 4 ships of 19273 TEU ship represented by *COSCO SHIPPING CAPRICORN* with a net tonnage of 193,505 tons. The cost of the ship is 200 million US dollars, with a speed of 22.5 knots, consumes 513 tons of fuel per day when sailing, 2 tons of diesel fuel per day when sailing, and 5 tons of fuel per day when berthing. There are 22 crew members.

About route parameters, from Shanghai to Rotterdam 1,501 nmiles, the annual one-way transport volume is 2.39 million TEU. Shanghai to Antwerp is 10,484 nmiles, and the one-way annual transport volume is 1.96 million TEU. Shanghai to Barcelona is 8,821 nmiles, and the one-way annual transport volume is 1.41 million TEU. Yantian to Southamp is 9,540 nmiles, and the one-way annual transportation volume is 2.27 million TEU.

All cargo on these routes may be transported by any of the above types of ships, and the annual operating time of various types of ships is 350 days, and they are directly transported back and forth on the above routes.

The port of Shanghai, Rotterdam, Antwerp, Barcelona, Yantian, Southampton, the loading and unloading efficiency are 55, 50, 48, 48, 53, 50 TEU per hour respectively.Each port has 4 equipment operations.

The price of fuel and diesel oil is the standard for marine diesel and fuel oil at Shanghai Port on December 2, 2019.The cost of running materials is calculated at 8% of the fuel cost, and the cost of materials is calculated at 10%.The annual idle cost of each type of ship is 3% of the ship price at the time of purchase.

The salary of the crew is calculated according to the average salary of them in December 2019.

Calculate the annual carbon emissions of various ship types on various routes through the carbon emission calculator of COSCO Shipping Lines,and the *maritime carbon tax* is calculated at US$25 per ton of $CO_2$.

Combining the above conditions, Table 2. and Table 3 can be obtained after calculating the annual operating cost of each ship type on different routes and annual transportation volume of each ship type.

**Table 2.** Annual operating cost of each ship on each route (million dollars)

| Route \ Type(TEU) | 19100 | 14100 | 20119 | 19273 |
|---|---|---|---|---|
| Shanghai to Rotterdam | 30.78 | 26.54 | 37.07 | 36.30 |
| Shanghai to Antwerp | 30.75 | 26.53 | 37.04 | 36.27 |
| Shanghai to Barcelona | 32.54 | 27.85 | 38.21 | 37.43 |
| Yantian to Southamp | 29.82 | 25.78 | 35.84 | 35.12 |

**Table 3.** Annual transportation volume of each ship type (Ten thousand TEUs)

| Route \ Type(TEU) | 19100 | 14100 | 20119 | 19273 |
|---|---|---|---|---|
| Shanghai to Rotterdam | 26.59 | 20.17 | 25.51 | 24.66 |
| Shanghai to Antwerp | 26.49 | 20.13 | 25.42 | 24.58 |
| Shanghai to Barcelona | 30.17 | 23.15 | 29.00 | 28.08 |
| Yantian to Southamp | 28.49 | 21.76 | 27.36 | 26.47 |
| Total | 111.73 | 85.21 | 107.28 | 103.78 |

According to the above model and simplex method, the optimal value of the objective function can be obtained US$236040.22. In addition, in the decision of the shipping company to build a new ship, 10 new 19100TEU ships can be added every year.

Through calculation, optimal wiring plan for ships in 2019 as follows.

**Table 4.** Optimal wiring plan for ships in 2019

| Route \ Type(TEU) | 19100 | 14100 | 20119 | 19273 |
|---|---|---|---|---|
| Shanghai to Rotterdam | 9 | 0 | 0 | 0 |
| Shanghai to Antwerp | 6 | 0 | 1 | 0 |
| Shanghai to Barcelona | 0 | 6 | 0 | 0 |
| Yantian to Southamp | 0 | 2 | 3 | 4 |
| Total | 15 | 8 | 4 | 4 |

## 4 Conclusion

Judging from the IMO and IEA statistics on carbon emissions from the shipping industry, carbon emissions reduction in the shipping industry cannot be delayed. In response, the European Union proposed to levy a *maritime carbon tax*, using the method of increasing the cost of carbon emissions to achieve carbon emission reduction in the shipping industry. As a result, *maritime carbon tax* will become another operating cost of shipping companies. Therefore, this article adds the operating cost of carbon emissions to the annual operating cost of the shipping company. With the goal of minimizing the total annual operating cost, a linear optimization model is established. In the practical sense of investigating the model, this paper selects the actual operating conditions of the four types of ships of COSCO SHIPPING in 2019 on the four routes respectively for calculation examples. Finally, the minimum annual operating cost of the shipping company and the corresponding route allocation plan can be obtained .

In addition, in the context of green shipping, the model can also be applied to the background of the Sulfur reduction, adding sulfur emission variables to solve practical problems. Similarly, it can also be applied to the reduction of nitrogen oxides.By combining these environmental constraints with practical problems, the sustainable development of society can be realized while protecting the environment.

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