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An Approach to the Economics of the Port's Double-Layer Container Rail Transportation

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Abstract

Port gathering and transportation involves a variety of transportation methods, and the economic distance and economic loading (full load rate) of each transportation method are different, that is, the technical and economic indicators are different. This article uses the economic loading concept of transportation economics and distance economic theory to focus on economies of scale and demonstrates the economics of transportation by cost analysis methods. In this paper, this method is first used to determine the economic distance and volume range of water, iron and public transportation modes, quantitatively analyze the advantages and disadvantages of railways in port transportation, and then further determine the economic indicators of railway double-layer containers and analyze the railway double Whether the layered container has achieved an advantage breakthrough on the basis of traditional railway transportation. Example analysis The Ningbo-Shaoxing port gathering and transportation line results show that the railway has an advantage over the road in terms of transportation volume, but at the same time is limited by the transportation distance; railway double-layer containers will further expand railway transportation volume, and railways also have advantages in short-distance gathering and transportation. This article provides a brand-new idea and method for demonstrating the economics of the port's double-layer container railway transportation.

Keywords: *Double-layer container; Railway transportation; Economic distance; Economic load*

I. Introduction

Port gathering and evacuation is mainly to gather and evacuate goods for the port, and closely connect water transportation with land transportation. The gathering and transportation mode mainly includes various transportation modes such as railway, highway and inland river, and each transportation mode has different technical and economic characteristics. The road transportation is highly mobile, troad network is dense, the coverage is wide, and the initial capital investment is small, the investment recovery period is short, and the equipment is easy to maintain. The disadvantages are high transportation cost, large unit energy consumption, small loading capacity of transportation vehicles, and the discharge of various pollutants has an obviously impact on the environment. Currently, road transportation is the most common in my country's ports, At present, highways transportation is the most common in my country's port gathering and transportation, according to relevant statistics, highways account for about 85% of the country's port container gathering and transportation volume; waterway transportation is superior to low cost, large transportation volume, strong stability, and extreme application, but the speed is not fast. Due to the greater impact of the weather, it has a greater dependence on other modes of transportation. At present, waterways account for about 14% of the container collection and transportation volume of ports in the whole country; railway transportation has a large loading capacity, strong continuous transportation capacity, and relatively low transportation costs. According to relevant statistical analysis in recent years, the overall proportion of my country's

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MTR collection and transportation accounts for only 2-3% of ports.

Railway double-layer containers are an important form of railway transportation. Experience has shown that double-layer container trains often start at the port and finally to the port, which can not only ensure sufficient cargo supply, but also play a role in the rapid accumulation of container flow and port shunting that cannot be achieved by road transport. For our country, at present, the development of port rail transportation is not perfect, and port double-layer container rail transportation is very inadequate. In 2015, the National Development and Reform Commission released the “Research on the Revision of Medium- and Long-term Railway Network Planning”, which optimized and adjusted the double-layer container aisle planning scheme, requiring the formation of a “five vertical and six horizontal” double-layer container aisle planning pattern with a total planned size of approximately 28,000 kilometers. The purpose of the plan is to achieve the leap-forward development of my country's railway freight transportation and narrow the gap with developed countries in the double-layer container transportation of railways. Different from the geology and landform dominated by plains in the United States, China's coastal areas are mountainous and hilly, and the railway construction cost is relatively high, which leads to the short-distance transportation within 300 kilometers of the railway transportation of coastal ports in my country, which increases transportation costs and further reduces the competitive advantage of railway transportation. For railway double-layer containers, it is obvious that the transportation volume is much larger than the railway transportation, but whether it is enough to make up for the disadvantages of the railway in short-distance transportation still needs further verification, the research done in this paper is based on this.

In the book "Transportation Economics", it is believed that my country's road transport has an advantage within 200 kilometers, and rail transport has an absolute advantage over 200 kilometers, transportation is more economical. This argument has no basis and no research to back it up, but it is regarded as a guide. Not only that, the theory of determining the transportation cost of various transportation methods by economic distance and economic loading is very scarce, even if occasionally, it is only a macro-qualitative, lacking the theoretical system and scientific basis. In order to directly reflect the economic advantages of railway double-layer containers, quantitative analysis should be taken. This paper first refers to the cost structure and technical and economic parameters of the collection and distribution mode to establish a cost analysis model to determine the economic distance and economic loading of each mode of transportation. In order to demonstrate the economy of railway double-layer container effectively, this paper compares and analyzes the economic distance and volume range of waterway, railway and highway of the three main types of container transportation, and quantitatively illustrates the advantages and disadvantages of railways in container transportation. Furthermore, the economic indicators of double-layer railway containers are calculated to verify whether double-layer railway containers can make up for the shortcomings of short-distance railway transportation, thereby explaining the significance of the leap-forward development of railway freight and providing reference for the construction planning of double-layer railway transportation networks.

II. Literature Review

This article uses economic haul distance theory and economic loading theory, and uses cost analysis method to determine the economic haul distance and economic load of transportation mode. Through searching a large number of documents, it is found that there are many studies related to transportation costs. But few researches are really helpful to determine the economic freight distance, especially the economic load. Only a few researches are related to the two, and the relevant literatures are sorted out as follows.

In terms of transportation cost, domestic and foreign scholars have conducted many researches from various influencing factors. Considering both fixed and variable costs, Saavedra-Nieves (2019) solves the problem of cost allocation caused by multiple cargo and EOQ strategies [1]. Zeng Zhixiong et al. took into account the four factors of delivery vehicle transportation, cold chain energy consumption, lychee loss and time window punishment to establish a cost model, and proved that the optimization model could realize the optimization of lychee cold chain logistics and distribution cost, so as to reduce the total logistics and transportation cost [2]. Wu Jun et al. (2016) analyzed the effects of transportation costs, cargo owner's subjective value differences, cargo owner's arrival rate, and changes in initial slot allocation on railway container transportation companies' optimal pricing and maximum expected returns, and proved the validity of the model with cases [3]. Zhang Qian et al. (2016) proposed a dual-target transportation cost model with time constraints, that is, the lowest number of transportation vehicles and the lowest transportation cost. and analyzed the feasibility of this model through a case [4].

In terms of economic haul distance, it mainly includes the research on the economic distance of goods transportation and the economic distance of engineering materials. In the transportation of goods, there are many different modes of transportation due to their different technical characteristics, resulting in different economic distance between modes of transportation. The mode of transport includes not only the traditional mode of transport, but also sea-rail combined transportation and container transportation. The representative academic papers mainly include: Xu Guangyan (2019) calculates the comprehensive transportation cost of loading different time value goods under the iron-public-water transportation method, and analyzes the impact of the time value of the goods on the economic distance of "door-to-door" transportation, The results show that it has a small impact on the comprehensive cost of public-rail transportation and a greater impact on waterway transportation [5]. Liu Yueting (2018) proposed the idea of an air mining machine to reduce the operating cost of open-pit mines by shortening transportation distance and improving mining efficiency [6]. In engineering material transportation, economic haul distance is considered to be the main influencing factor of engineering material transportation cost, and it is very common in engineering material cost research. In order to effectively reduce the transportation cost which affects the construction cost, how to determine the economical transportation distance of materials is studied. In related research, the determination methods of economic haul distance of engineering materials are different. The representative articles mainly include: Zou Hao (2019) introduced the significance of economic haul distance in detail considering that economic haul distance is an important factor for the generation of railway engineering freight and miscellaneous fees, and calculated the economic haul distance of engineering materials by using linear planning method [7]. Xia Yao (2017) considers the impact of actual construction engineering, introduced material consumption per kilometer of line engineering, and uses the calculus method to calculate the minimum value of the material cost, so as to obtain the boundary point of economic distance [8].

In terms of economic loading, there are relatively few existing research literatures, and most of them reflect the loading research in engineering design. Chen Yikai et al. (2018) studied the main factors of highway transport overload, based on data collection, using single factor analysis, collinearity test, binary logistic regression analysis, and concluded that freight volume and average distance are the main factors affecting road freight overload [9]; Xu Xingfang (1995) analyzed the existing problems of the current algorithm and proposed a revised algorithm for determining the maximum load of ultra-long cargo and its economical and reasonable loading calculation method[10]. Li Zhongxing (2011) converted the three-dimensional loading problem into a two-dimensional rectangular loading problem, and then used the mature two-dimensional rectangular loading technology to solve the loading problem, and realized the algorithm design and simulation of container loading [11]. Fang Shijie (1990) established an optimization model to calculate the loading of truck train materials at the lowest cost, and took it as a reasonable load of automobile and train [12].

III.Methodology

As can be seen from the laws that have formed in the transportation market, the most direct evaluation factor for demonstrating economics is the total cost. In this section, first of all, the components of the transportation cost model are given, reference port transportation main transportation mode, the technical and economic parameters of take the influence factors of the distance and traffic volume total transportation cost of calculation, and then discusses the port container transportation way in highway, railway, waterway and railway double-layer container economic haul, economic load.

3.1 Symbol Description

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Before the model is established, first define the meaning of some letters that appear in the model, as shown in the following Tab 1:

Table 1 Model symbols and meaning

symbol	implication
I_c	Investment costs including infrastructure
n	Service life of means of transport
i	interest rate
r	Discount Rate
L	Line length
V_s	Carrying tool running speed
Z_{sa}	Waiting time between two locations
Z_{bt}	Annual maintenance time
Z_{bk}	Annual idle time
Y_k	Cargo capacity
Y_d	Vehicle full load rate
B_f	Fuel consumption per kilometer (main + auxiliary)
P_f	Fuel prices
B_o	Lubricant consumption per kilometer (main + auxiliary)
P_o	Lubricant price
e_f	Future fuel cost increase
C_{mo}	Annual operating and maintenance costs
e_m	Future increase in operating and maintenance costs
S	Percentage of insurance (% I_c)
e_s	Future insurance cost increase
c_{ac}	Cost of accident
c_p	The cost of pollution caused by emissions
c_n	Cost of pollution caused by noise
e_x	Future increase in external costs

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Y_d^*	Rated full load rate of external cost

3.2 Assumptions

The actual situation of container transportation is very complex, so it is impossible to cover all aspects when establishing the model. Therefore, it is necessary to abstract some factors and links, assumptions should be made to simplify the model.
(1) Container railway transportation is a special line for container cargo;
(2) Investment cost is the construction cost of infrastructure or transportation means;
(3) In order to facilitate the calculation of this paper, this article does not consider the cost of personnel and the cost of loading and unloading machinery;
(4) The annual interest rate is 8%;
(5) The future fuel cost will increase by 5%;
(6) The future operation and maintenance costs will increase by 3%;
(7) The future external cost will increase by 3%;
(8) The annual discount rate is 10%;
(9) The rated full load rate of external costs is 70%;
(10) Future insurance costs will increase by 3%.

3.3 Objective function

This model is only used to calculate the unit container freight transportation cost, and does not involve passenger transportation and ferry car transportation. The loading capacity and transportation distance are taken as optimization objectives, and a multi-objective optimization model based on unit transportation cost is established. This article divides the transportation costs of water, iron and public transportation into: capital, fuel and lubricant costs, operation and maintenance costs, and other external costs. The total transportation cost per unit of goods is shown as follows:

$$U_T = \sum U_i = U_c + U_m + U_f + U_{ex} \ (\text{yuan}/ton) \tag{1}$$

The transportation cost UTL per unit per kilometer is:

$$U_{TL} = \frac{U_T}{U_L}\left(\text{yuan / ton} \cdot \text{km}\right) \tag{2}$$

(1) Investment cost per container cargo
The unit cost of unit investment Uc expressed in units is as follows:

$$U_c = \frac{\sum_{t=1}^{n} C_k(t)(1+r)^{-t}}{Y_s \sum_{t=1}^{n} (1+r)^{-t}} \tag{3}$$

Combining the investment cost formula and the freight transport volume formula with the above formula, the unit cost investment formula for the related technical, economic and operational parameters is obtained as follows:

$$U_c = \frac{\left\{\sum_{t=1}^{n} I_c\left[\left(1-\left((t-1)/n\right)\right)i + (1/n)\right](1+r)^{-t}\right\}\left[2L + V_s Z_{sa}\right]}{2Y_k Y_d V_s \left(8760 - Z_{bt} - Z_{bk}\right)\sum_{t=1}^{n}(1+r)^{-t}} \tag{4}$$

The unit investment cost of container cargo Uc mainly depends on the loading capacity, transportation distance, and the choice of transportation means, considering the service life of the transportation means, the annual depreciation rate and annual interest rate of the transportation means purchased.

(2) Fuel and lubricant costs per unit of cargo

$$U_f = \frac{\sum_{t=1}^{n} C_f(t)(1+r)^{-t}}{Y_s \sum_{t=1}^{n}(1+r)^{-t}} \tag{5}$$

Similarly, considering the investment cost formula and cargo transportation volume formula, the fuel and lubricant cost formula per unit cargo is as follows:

$$U_f = \frac{\left(B_f P_f + B_o P_o\right) L \sum_{t=1}^{n}\left[\left(1+e_f\right)^t (1+r)^{-t}\right]}{Y_k Y_d \left[\sum_{t=1}^{n}\left[(1+r)^{-t}\right]\right]} \tag{6}$$

The cost of fuel and lubricant U_f per unit of cargo mainly depends on the transportation method, distance and loading capacity.

(3) Operation and maintenance costs per unit of goods

As above, the average operating and maintenance cost U_m of unit cargo is:

$$U_m = \frac{\sum_{t=1}^{n} C_m(t)(1+r)^{-t}}{Y_s \sum_{t=1}^{n}(1+r)^{-t}} \tag{7}$$

By considering the annual operation and maintenance costs and time-related costs, considering the depreciation of the initial investment cost of the transportation vehicle during its economic life, the operation and maintenance costs of the unit cargo are:

$$U_m = \frac{\left\{\sum_{t=1}^{n}\left[C_{mo}\left(1+e_m\right)^t + \left(sI_c\left(1-(t/n)\right)\right)\left(1+e_s\right)^t\right](1+r)^{-t}\right\} \times \left[2L + V_s Z_{sa}\right]}{2Y_k Y_d V_s \left(8760 - Z_{bt} - Z_{bk}\right)\sum_{t=1}^{n}(1+r)^{-t}} \tag{8}$$

The unit maintenance and operation cost Um is mainly related to the transportation distance and transportation method. Different means of transportation have different means of transportation, so different means of transportation have different insurance rates, prices and technical characteristics.

(4) External costs of unit goods

The external cost per unit of cargo considers the cost of accidents, the cost of pollution caused by emissions and the cost of pollution caused by noise, and the annual rate of increase in external costs. Related expressions are:

$$U_{ex} = \frac{\left(c_{ac} + c_p + c_n\right) L \sum_{t=1}^{n}\left(\left(1+e_x\right)/(1+r)\right)^t}{\left(1+e_x\right)\sum_{t=1}^{n}\left[(1+r)^{-t}\right]}\left(\frac{Y_d^*}{Y_d}\right) \tag{9}$$

Among them, C_{ac}, C_p and C_n are the cost of accidents, the cost of pollution caused by emissions, and the cost of pollution caused by noise. Yd* is the reference fullness ratio used to calculate external costs, and ex is the rate of rise of external costs.

In summary, the total cost of unit container cargo transportation is as follows, the model covers all general formulas for cost analysis.

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$$U_T = \frac{\sum_{t=1}^{n}\left[I_c\left[\left(1-\left(\left(t-1\right)/n\right)\right)i+\left(1/n\right)\right]+2LS_s\left(B_f P_f + B_O P_O\right)\left(1+e_f\right)^t + C_{mo}\left(1+e_m\right)^t + sI_c\left(1-\frac{t}{n}\right)\left(1+e_s\right)^t\right]\left(1+r\right)^{-t}}{2Y_k Y_d S_s \sum_{t=1}^{n}\left(1+r\right)^{-t}} + \frac{\left(c_{ac}+c_p+c_n\right)L\sum_{t=1}^{n}\left(\left(1+e_x\right)/\left(1+r\right)\right)^t}{\left(1+e_x\right)\sum_{t=1}^{n}\left[\left(1+r\right)^{-t}\right]}\left(\frac{Y_d^*}{Y_d}\right) \tag{10}$$

IV. Case Study——Taking Ningbo-Shaoxing Transportation Line as an Example

4.1 Data collection

For the transportation cost, the Ningbo-Shaoxing regional transportation route was selected, and the economics of different transportation methods were selected. For the cost analysis method of the above model, the following collects the current data of investment cost, fuel and lubricant cost, operation and maintenance cost, and external cost of each transportation method. The cost of electricity consumed by electrified transportation is replaced by fuel costs. Assume that under all modes of transportation, the interest rate i is 8%, the discount rate r is 10%, the future fuel cost increase e_f is 5%, the future operating and maintenance cost increase e_m is 3%, and the future external cost increase rate e_x 3%. In my country, the research and data on external cost estimation for different modes of transportation are not accurate. Therefore, referring to the results of available data analysis in various regions, estimates were made for different modes of transportation to obtain the external cost data shown in Tab 2. This article selects a standard model that meets the conditions of the Ningbo-Shaoxing transportation section: the section is suitable for the use of container ships with a water transportation of 3000 TEU, freight trains with a railway transportation capacity of 700 tons, and double-layer container transportation capacity of 1120 tons with railway transportation. Trucks with a transport capacity of 20 tons. All technical and economic parameters of these vehicles are summarized in Tab 3.

Table 2 Specific external cost data

environmental impact	Water transporta -tion yuan/(ton•km)	Railway yuan/(ton•km)	Highway yuan/(ton•km)
c_{ac}	$4.2*10^{-4}$	$2.8*10^{-3}$	$2.31*10^{-2}$
c_p	$2.695*10^{-3}$	——	$3.15*10^{-3}$
c_n	——	$1.05*10^{-3}$	$1.54*10^{-3}$

Table 3 Related technical and economic characteristics of transportation

symbol	unit	water transport	Railway single-layer transportation	Road transport	Railway double-layer transportation
I_c	yuan	42000000	45500000	630000	60000000
n	year	20	20	10	20
i	——	8%	8%	8%	8%
L	km	1000	1000	1000	1000
r	——	10%	10%	10%	10%
V_s	km/h	24	35	50	120
Z_{sa}	hour	9	30	6	30

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Z_{bt}	hour	300	1200	720	1200
Z_{bk}	hour	1095	1095	5110	1095
Y_k	t	3000	700	20	1120
B_f	rise/km	16	7	0.3	7
P_f	yuan/rise	2.1	7	7	7
B_o	rise/km	0.11	0.05	0.0036	0.1
P_o	yuan/rise	7.7	38.5	38.5	38.5
e_f	——	5%	5%	5%	5%
C_{mo}	yuan/year	5250000	5600000	105000	5600000
e_m	——	3%	3%	3%	3%
S	yuan	0.14	0.06461	0.19446	0.06461
e_s	——	3%	3%	3%	3%
e_x	——	3%	3%	3%	3%
Y_d^*	——	70%	70%	70%	70%

Source: Ningbo Port Authority; wiki.mbalib.com; Bahri S , Huseyin Y, Yasin U, et al. An Approach for Economic Analysis of Intermodal Transportation; China Railway Group Internal Data

4.2 Model calculation

The operation-related data can be obtained from the following Fig 1 to 4. Fig1 to 4 represent the container waterway, highway, railway single-layer and railway double-layer container transportation under different loading capacity and distance conditions. The calculated unit container freight transportation cost.

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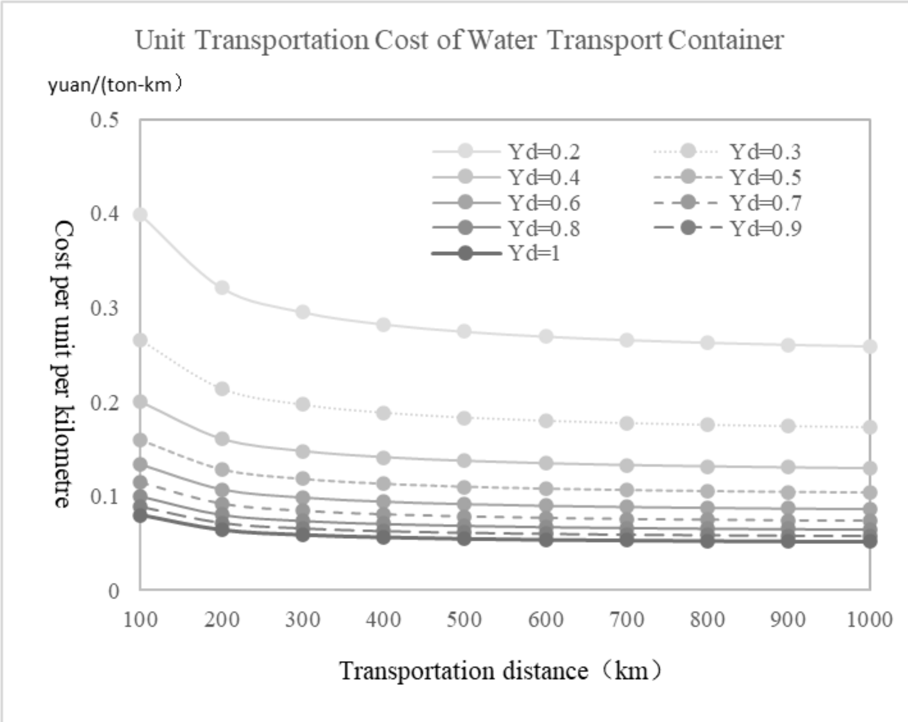

Fig.1 Container transportation cost of water transportation unit

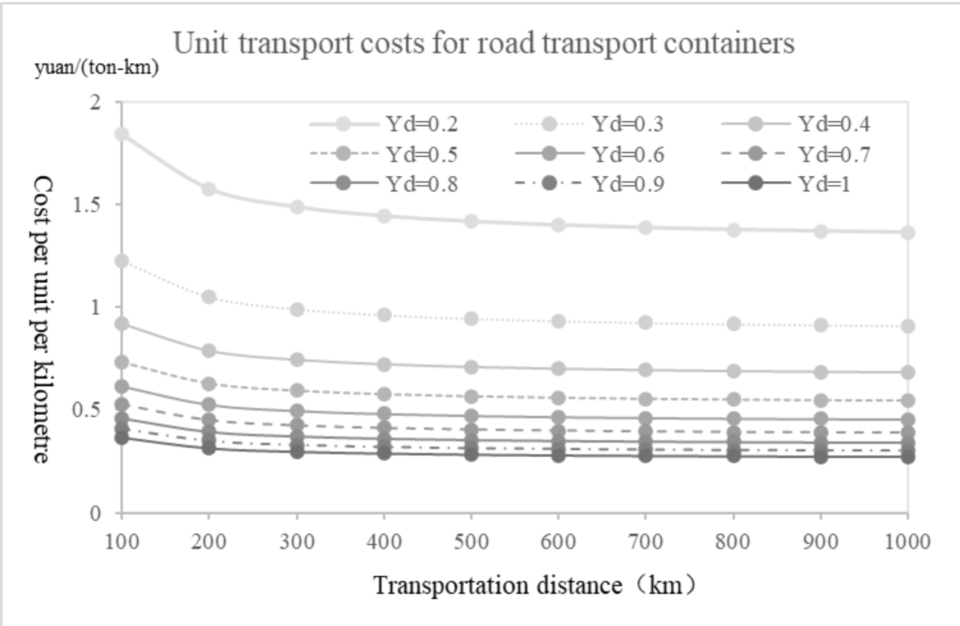

Fig.2 Road transportation unit container transportation costs

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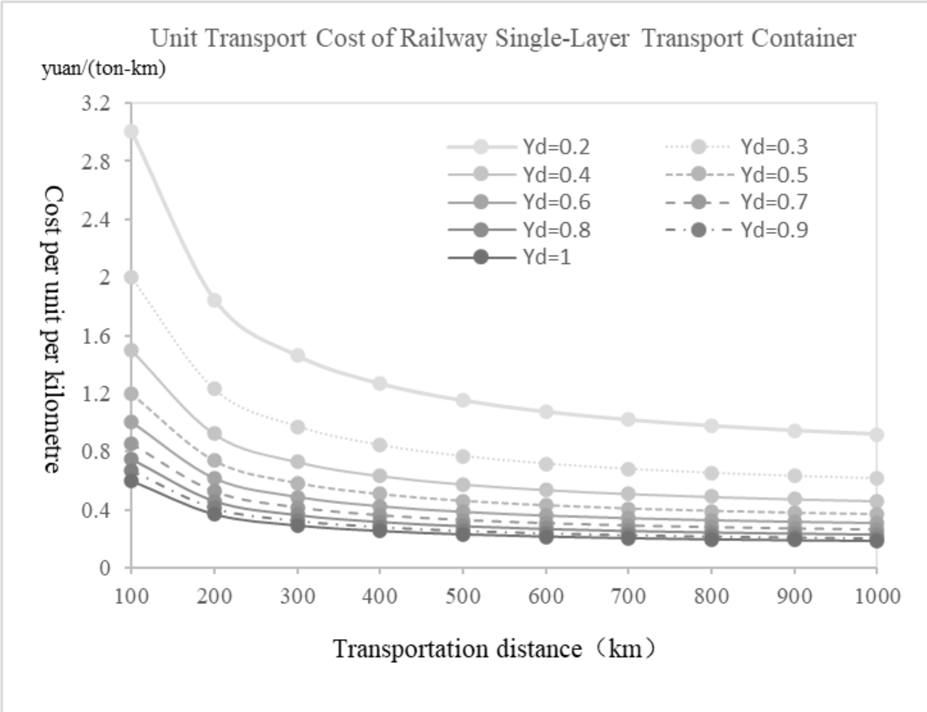

Fig.3 Container transportation costs of railway single-layer transportation units

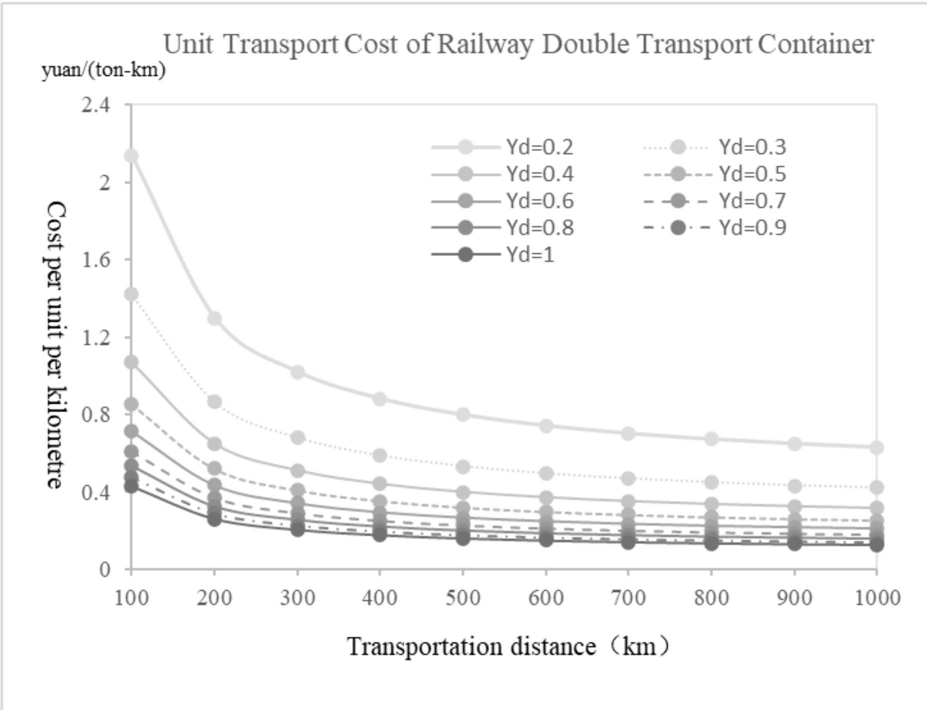

Fig.4 Container transportation cost of double-layer railway transportation unit

4.3 Result and Discussion

It can be seen from Fig.1 to Fig.2 that the transportation cost of each port's collection and distribution mode has the same trend when the loading rate changes, that is, the greater the full load rate, the smaller the unit container freight transportation cost. When the full load rate is close to or when it is greater than 80%, the transportation cost will no longer change significantly, so the economic loading capacity of each transportation mode is considered to be the transportation capacity at the full load rate of 80%. It is calculated that the economic loading capacity of waterway is 2400t, highway is 16t, single-layer container is 560t and double-layer container is 896t. The economic loading capacity can intuitively reflect the upper limit of the transportation volume of the transportation method, and then indirectly reflect the economic efficiency of the transportation method in terms of transportation volume through the ratio with the fixed cost. Obviously, waterway is the most advantageous route in terms of traffic volume, followed by railway double-layer container, then single-layer railway, and the least advantageous route in terms of traffic volume. The following will analyze the distance independently based on the above conclusions, and further explore the economics of railway single-layer and double-layer containers.

(1) Economic analysis of railway single-layer containers
Fig.5 compares the unit container freight transportation costs of waterway, railway single layer and road transportation. It can be seen from the figure that, under the condition of a certain volume of traffic, the cost of waterway transport per container is always lower than that of single layer of highway and railway. However, waterway transport is more limited by geographical environment, and the Ningbo-Shaoxing collection and distribution route is short, so it is not suitable to carry out waterway transport. Therefore, waterway transport is not compared and analyzed on this route.

When the transportation distance is 300km, the relative transportation cost of railway single-story and highway is the same. When the haul distance is less than 300km, the cost of road transport is less than that of railway, which has more economic advantages. Therefore, it is considered that the economic haul distance of road transport is less than 300km. When the haul distance is greater than 300km, the single-layer railway transport cost is lower than that of road. This is mainly because the fixed cost of railway is higher than that of road, but the freight volume of railway has advantages, so that the railway transport distance has more economic advantages when it reaches more than 300km. In summary, the economic haul distance of a single-story railway is greater than 300km. From this, it can be seen that the advantage of rail traffic volume is limited to a certain extent by the haul distance, which is not suitable for short-distance transportation of port gathering and transportation. Considering that most of the collection and distribution lines in China's coastal ports are short-distance transportation, it is very unfavorable to develop the collection and distribution mode of port railway.

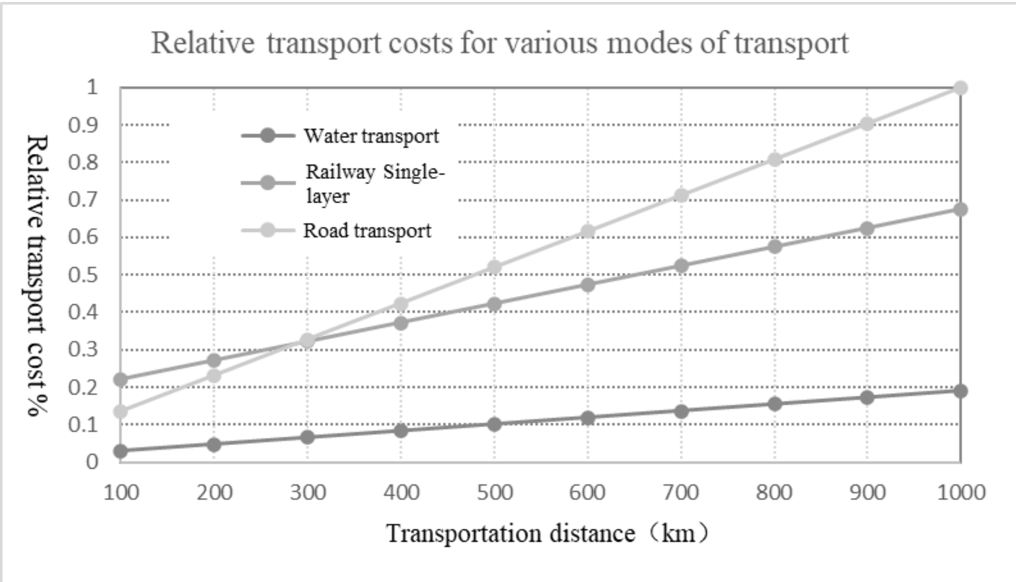

Fig.5 Railway single-layer container economy

(2) Economic analysis of double-layer railway containers
Fig.6 compares the transport costs of container goods per unit of waterway, railway and road transport. It can be seen

from the figure that the economic distance of the highway is within 120km, and the economic distance of the double-layer container of the railway is greater than 120km, which expands the economic distance of railway transportation. On my country's coastal port gathering and transportation lines, most of the lines have a transport distance of more than 120km, which is suitable for double-layer container transportation by rail, which fully shows that double-layer containers can make up for the disadvantage of railway transportation distance in port gathering and transportation. However, in my country should take the lead in the development of double-layer railway containers in the field of railway freight transportation. On the one hand, because the single-layer railway containers are subject to the disadvantage of transportation distance, they cannot adapt to the current freight structure in my country; On the other hand, in the process of port collection and distribution, railway double-layer containers will further improve the railway traffic volume, so that it will not be restricted by the distance, which is not only suitable for China's national conditions, but also an inevitable choice for the sustainable development of railway freight.

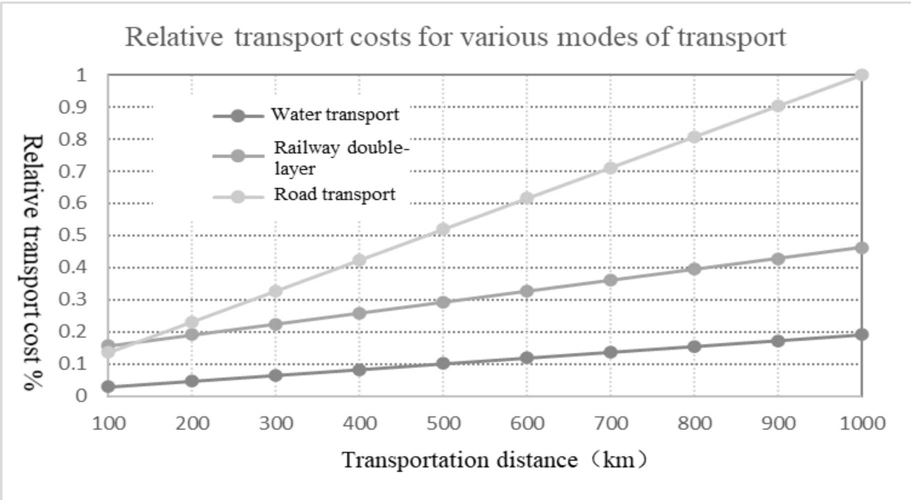

Fig.6 Railway double-layer container transportation economy

V. Conclusion

Mode of double-layer container port railway transportation economy, this paper studies and puts forward a new economic reasoning methods, namely the comprehensive consideration of the mode of transportation cost and the technical and economic parameters, transport costs can be divided into capital, the cost of fuel and lubricating oil, operation and maintenance costs, and other external costs, through the cost analysis finally determine the port economic haul, economic load transportation way. In the process of demonstrating the economics of double-layer containers, first of all, the three main modes of transportation in port gathering and distribution are waterways, highways and railways, and quantitative methods are used to analyze the advantages and disadvantages of railways. Further calculate the economic indicators of the railway double-layer container to demonstrate whether it has achieved an advantage breakthrough on the basis of the railway and is more economical than other transportation methods.

The case analysis of Ningbo-Shaoxing Gathering and Distributing line shows that, in the way of port Gathering and Distributing mode, the railway single-layer container has advantages in volume, but when the distance is less than 300km, the railway is less economical than the road, and lacks competitiveness in the port collection and distribution in my country. The railway double-layer container expands the freight volume advantage of the railway single-layer container, at the same time, expands the economic haul distance of the railway to more than 120km, making up the disadvantage of the railway in the haul distance. The results of this study fully prove that railway double-layer containers are more economical, and China should vigorously develop railway double-layer containers to realize the leap-forward development of railway freight.

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