Predict Port Throughput Based on Probabilistic Forecast Model

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Abstract. When the service region of ports overlap, consignors' selecting behaviors for shipping ports become homogeneous to commuters' choosing behaviors on trips. The commuters' travel behaviors can be described through a probabilistic model in transportation planning. In this study, we adopt the transportation probabilistic forecast model to forecast port throughput. First, we amend the model with a port attraction coefficient to forecast port throughput distributions between different ports. Then, forecast for each port throughput is obtained by reallocation of regional total port throughput to each nearby port. We use the port of Fuyang as an empirical research in this paper to validate the methodology. Results compared between this method and traditional regression model indicate that this method provides more persuasive reasoning.

Keywords: Port throughput · Probabilistic forecast model · Port attraction coefficient · Cargo distribution

1 Introduction

The inland waterways freight transport is an economic and environmental friendly transport mode. Development of in land waterway transport, especially for freight transport, not only promotes economic development, but also controls environmental pollution [1]. Port throughput forecast is an important part of shipping development planning. In recent years, with the accelerated process of urbanization in China, the distance between cities along the inland waterways is gradually reduced. Therefore, the distance between inland ports is as well decreased. Overlapping phenomenon appears more and more often between adjacent ports. Cargo shippers in these overlapping areas have more choices. Consignors' selection between ports becomes similar to commuters' choice of route for trips. In transportation research, probability model is usually used to predict commuters' choice for potential travel routes.

In this study, by both drawing from the travel route choice probability model in traffic planning and introducing the port attraction coefficient, we build a shipper-to-port selection model. The throughput of each port is obtained by reallocating the regional total port through to each nearby port.

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2 Literature Review

Numerous scholars performed multi-angle studies on the forecast of port cargo throughput using traditional mathematical model, intelligent algorithms, and some other methods [2]. Traditional models perform statistical analysis to resolve the relations between port throughput and a variety of affecting factors by using conventional mathematical methods. In forecasting the Northern Guangxi Port logistics demand, Wang et al. [3] utilized a cubic exponential smoothing method. Chou et al. [4] adopted a modified regression model to forecast the amount of containers imported from Taiwan. de Gooijer and Klein [5] forecasted the incoming steel traffic counts at the port of Antwerp using multivariate time series model.

Due to the extensive use of intelligent algorithms in transportation research, as well as the great enhancement in computing capacities, a variety of intelligent algorithms have been adopted to the forecast of port throughput. Wei et al. [6] used artificial neural network to forecast the number of containers at the port of Kaohsiung. Based on LSSVR, Xie et al. [7] applied mixed model for port throughput forecast. Xiao et al. [8] forecasted port container throughput using Particle Swarm Algorithm. Xu and Wang [9] forecasted the cargo throughput for the port of Qingdao based on TEI@I methodology. Huang et al. [10] as well forecast container throughput for the port of Qingdao using mixed model. Reside on the theory of Markov and Gray forecast model, Zang et al. [11] forecasted waterway freight volume in Chongqing. Linsheng et al. [12] used a combination of multiple linear regression method and the BP neural network to study the Fangcheng port throughput.

Combination of different forecasting methods provides good forecast model for port throughput, but only a few of them involves competition between ports that are geographically adjacent or located in the same region. With the acceleration of urbanization process in China, the scale of urban land is growing. Towns are getting closer, and the distance between ports is decreasing. The rapid development of land transportation, consignors are able to select from more distant ports to ship goods. Thus, competition arouses between geographically adjacent ports. When forecast port throughput, the consignors' selective mind must be taken into account in order to reassign the port cargo throughput effectively. For such situation, Yuan and Xie [13] introduced the selection probability theory to construct a negative exponential model, which was used to forecast port cargo throughput. Liu and Chen [14] further modified the travel mode choice model based on the accessibility theory to improve the forecast accuracy. In our study, we establish a throughput allocation model based on the probability theory to obtain regional total port throughput, and then reallocate it onto each nearby port.

3 Probability Distribution Model

In transportation research, travel time or travel distance is often being utilized as impedance. Usually, commuters choose the shortest route when facing with multiple choices. However, due to the constantly changing traffic conditions, commuters have limited information on traffic. It always results in rather longer route choices. In fact, there is a higher probability that commuters choose shorter routes. The probability of choosing each possible route can be calculated using LOGIT route choice model. Based on such knowledge, probabilistic route choice model has been constructed for transportation research purposes as follow [15]:

$$P(r,s,k) = \exp[-\theta \cdot t(k)/\bar{t}] \Big/ \sum_{i=1}^{m} \exp[-\theta \cdot t(i)/\bar{t}] \tag{1}$$

Where:

P (r, s, k)	represents the share of transportation mode k from area r to area s;
t(k)	represents the impedance of route k;
$\bar{t}$	represents average impedance of each route;
θ	represents the undetermined coefficient;
m	represents the numbers of valid travel routes.

The shipping cost of goods can be divided into three segments, cost of delivery from the origin point to departure port, cost of shipping from departure port to destination port, and cost of delivery from destination port to final destination. When there are several choices at the point of origin where ports locate relatively close to each other, the cost from departure port to destination port and the cost from destination port to final destination are relative less distinctive. The major distinctive cost of choosing different ports is relaying on the cost of delivery from origin to the departure port. This cost can be treated as traffic impedance for goods transportation to the port. According to function (1), we build port selection model as follow:

$$p_{kj} = \frac{e^{-\theta t(k)/\bar{t}}}{\sum_{i=1}^{n} e^{-\theta t(i)/\bar{t}}} \tag{2}$$

Where:

P_{kj}	represents the probability of consignor in area k choose port j;
t(k)	represents the impedance function of goods transportation;

The impedance function comprises two parameters, the generalized to-port cost (E_{ij}) and the port attractiveness coefficient (A_j) which reflects the port characteristics:

$$t(k) = E_{ij}/A_j \tag{3}$$

E_{ij} represents the generalized to-port cost;

Generalized to-port cost is the cost of transport from the origin point i to port j. It includes cargo transport cost, transfer cost, cost of time, and other indirect costs.

A_j represents the port attractiveness coefficient;

The port attractiveness coefficient reflects the attraction of the port to consignors. It is mainly affected by the accessibility, shipping prices, service levels, and etc. Among all of those factors, accessibility plays a decisive role. Port accessibility can be measured using average distance of cargo transport to this port, which is calculated as a rate of port turnover over port throughput.

$\bar{t}$ represents average impedance to each port;
θ represents the distribution parameter; In practical application, the average value is between 3.0 and 3.5. We select the value of 3.3 representatively [15];
n represents the number of ports.

4 Case Study

Fuyang City is located in the northwest of Anhui Province. Based on the Fuyang City Master Plan (2012–2030), the city will build two major ports, the Fuyang port and the Yingshang port, and four 4 regular ports, the Taihe port, the Jieshou port, the Linquan port, and the Funan port. From 2011 to 2015, the city's total port throughput is 49,124,400 tons. Comparing to the period between 2006 and 2010, the total throughput grew by 184%. From 2016 to 2020, 2.65 billion yuan has been budgeted to invest in port construction hoping to reach 10 million tonnage increase [16].

Due to the shortage of statistics for Funan port, this study will only study the ports of Fuyang, Taihe, Yingshang, Jieshou, and Linquan. The layout of each port is shown in Fig. 1. All five ports are located relatively close to each other within the administrative divisions of Fuyang. They have a large overlapping hinterlands area. The cargo shipper may choose any port. This is a typical situation where ports compete within one region.

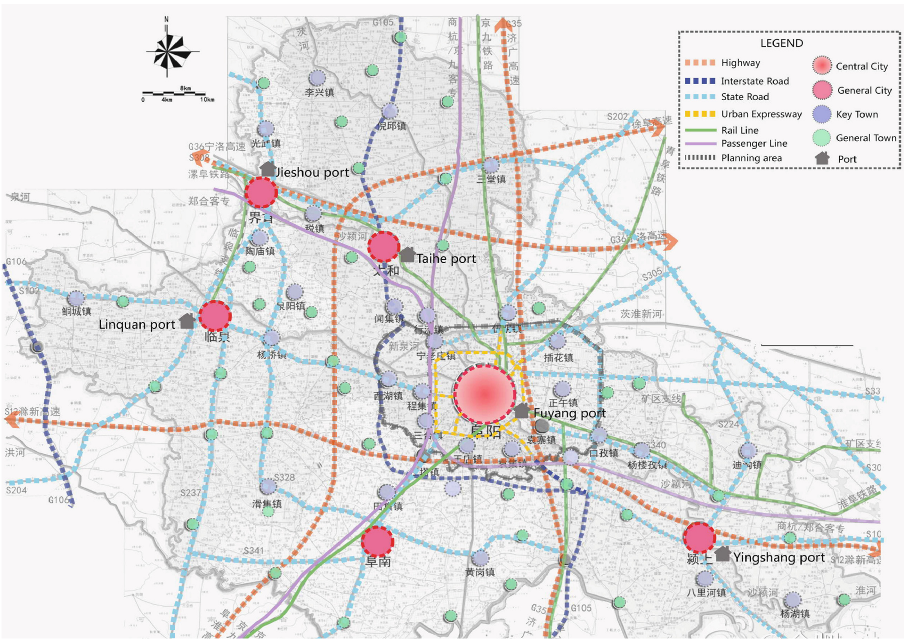

Fig. 1. Layout of Fuyang ports

The cargo throughput in recent years in ports of Fuyang is shown in Table 1.

Table 1. Fuyang City Port cargo throughput statistics (2006–2014) (unit: 10,000 tons) (Source: "Statistical Yearbook of Fuyang City", "China Port Yearbook 2012 Edition", www.soshoo.com)

Year	Total	Fuyang port	Linquan port	Taihe port	Yingshang port	Jieshou port
2006	189	49	17	49	48	26
2007	290	43	20	96	77	55
2008	453	105	18	103	111	114
2009	366	83	23	128	86	46
2010	430	102	33	147	98	50
2011	509	108	47	105	201	48
2012	681	121	61	62	356	46
2013	1020	229	118	151	434	88
2014	1311	417	120	157	522	96

Using the trend analysis, according to the data of Table 1, the relationship between the cargo throughput and time is obtained as follows:

$$y = 122.04x - 21. \tag{4}$$

where

y: cargo throughput, unit: 10,000 tons,
x: year.

By using formula regression analysis above, correlation coefficient is R2 equals to 0.84, indicating that the correlation is very well. Based on this formula, the total throughput of Fuyang port will be 18.09 million tons in 2020. This result is comparable with the 18 million tons prediction in the literature [17] (Fig. 2).

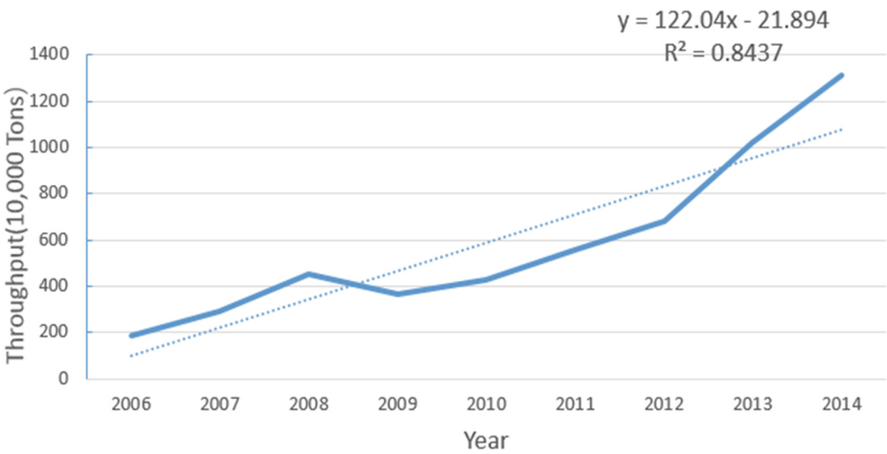

Fig. 2. Port throughput for Fuyang prediction regression analysis chart

The hinterland of Fuyang is relatively small. Most cargos transported by land transportation to the ports. Usually, there is no transfer cost within this area. The generalized to-port cost can be treated as the cost from origin to departure port. In the study region, shipping prices between ports are comparable. The port attractiveness coefficient is obtained from the ratio of the port turnover.

$$\mathrm{Aj} = \mathrm{F}/\mathrm{T} \tag{5}$$

F represents the average freight turnover volume over past years,
T represents the average cargo throughput over past of years.

Table 2 shows the freight turnover volume of each port in Fuyang in the recent years.

Table 2. Statistics of the freight turnover volume for Fuyang port (2006–2014) (unit: 10,000 tons). (Source: "Statistical Yearbook of Fuyang City", www.soshoo.com)

Year	Total	Fuyang port	Linquan port	Taihe port	Yingshang port	Jieshou port
2006	95370	16793	7385	27973	30030	13189
2007	156494	15152	11085	53077	45627	31553
2008	129841	9586	9883	16999	58501	34872
2009	73881	9873	8308	9491	38568	7641
2010	87466	11688	9836	11236	45660	9046
2011	87372.5	9069	9915.5	6093	55613	6682
2012	87279	6450	9995	950	65566	4318
2013	86549	8006	12219	3090	61974	1260
2014	107085	18874	12452	741	74623	395

The attractiveness coefficient of each port is calculated according to Eq. (3) using data in Tables 1 and 2. Table 3 shows the results.

The port cargo throughput in 2020 is calculated through GIS according to function (1). And the throughput of each port is predicted through the traditional linear regression mode. The traditional linear regression of each port are in Table 4. The results of two models are shown in Table 5.

Table 3. Results of the average cargo throughput, freight turnover volume, and attractiveness coefficient of each port. (Unit: 10,000 Tons)

Name	Average throughput	Average freight turnover	Port attractiveness coefficient
Fuyang port	140.10	11721.22	83.66
Linquan port	50.77	10119.83	199.34
Taihe port	110.90	14405.56	129.90
Yingshang port	217.72	52906.89	243.00
Jieshou port	63.22	12106.22	191.48

Table 4. The linear regression of each port

Name	Linear regression function	R^2
Fuyang port	$y = 34.829x - 34.042$	0.6653
Linquan port	$y = 13.585x - 17.156$	0.8117
Taihe port	$y = 8.1537x + 70.131$	0.3367
Yingshang port	$y = 59.951x - 82.035$	0.8621
Jieshou port	$y = 4.0838x + 42.804$	0.1489

Table 5. The port cargo throughput in 2020 based on two model (Unit: 10,000 Tons)

Name	Fuyang port	Linquan port	Taihe port	Yingshang port	Jieshou port	Total
Throughput by Eq. (1)	520	198	220	750	181	1869
Throughput by Linear regression function	488	187	190	817	104	1786
Error value	0.06	0.06	0.14	-0.09	0.43	

5 Discussion

(1) There are many factors that affect the attraction of the ports, and the accessibility plays a major role. The port of Fuyang and the port of Yingshang are located in the central area. They are well connected with the industrial land use and storage land use. The two ports are therefore more attractive to cargos.

(2) The turnover of the port reflects its shipping scope. The greater the turnover, the greater the attraction. The port of Yingshang has the largest turnover mileage. Although its location is less favorable than the port of Fuyang, it is the most attractive port.

(3) There are differences between the results predicted by the probability distribution model and the results forecasted by traditional linear regression model. Overall, the smaller the R2 value of the linear regression model, the greater the difference. It indirectly proved that the probability distribution model is more reliable.

(4) By analyzing the port throughput at different locations, the port attraction coefficient and port accessibility are found to be the most influential factors to the throughput. This finding is in accordance with the basic laws of transportation. Also, these two factors can be used as important basis for the port site selection and construction planning.

(5) In this study, the determination of the impedance coefficient is relatively simple. It is only based on road length as the basis for calculation instead of using cost of travel time in land transportation. The determination of the port attraction ignores the evaluation criteria of the port service and the port infrastructure. The two parameters can be further analyzed in follow-up studies.

6 Conclusion

In a certain area, the behavior of cargo shippers' selection of a port is similar to that of the commuters' choice of a trip route. In this study, we adopted the probability choice model from transportation planning to construct a distribution model for port throughput. We then applied this model to forecast the throughput of Fuyang port. Results are compared with the traditional regression model. It indicates that our model provides more explanatory logistics and more reasonable results. This study can as well provide reference for ongoing and future ports planning and construction.

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