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Analysis of the Development Potential of Bulk Shipping Network on the Yangtze River

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Abstract

In the past decades, a multi-layer transshipment network of bulk shipping has been formed along the Yangtze River so as to support the fast development of Chinese iron and steel industry. Yet with the decrease of iron ore trade in China since 2014, the bulk port system on Yangtze River probably will be subject to change in the future. Under this background, this paper aims to analyze the development potential of Yangtze River bulk ports system with a focus on iron ore transshipment. To realize this objective, we firstly sort out the main transshipment patterns of bulk shipping, and optimize the bulk-shipping network with an optimization model. Several scenarios are then proposed and examined in the model by changing corresponding parameters. Cooperation among ports as one scenario is analyzed by applying core theory in cooperative game. Based on the changes of transshipment plans observed under the various scenarios, we finally ascertain the different development potentials of the system, and provide suggestions to the port operators and local maritime authorities.

Keywords

Inland river port system, Bulk shipping network, Optimization model, Core theory, Strategy analysis and policy implication

1. Introduction

Since China's reform and opening up in the early 1980s, steel manufacturers along the Yangtze River, like Baosteel Group in Shanghai (founded in 1978), Shagang Group (1975) and Nanjing Iron and Steel Group (1958) in Jiangsu, Ma'anshan iron & steel group corporation in Anhui (1953), Wuhan Iron and Steel Group (1958) in Hubei, and Chongqing Iron and Steel Group (1997) have taken off in succession. The iron and steel industry along the Yangtze River has entered an era of booming. As an evidence, the total throughputs of import iron ore at the main ports along Yangtze river increased from 1.6 million ton in 1989 to 85.3 million ton in 2014, the figure of Shanghai increases from 6.6 million ton in 1989 to 49.6 million ton in 2014. In China, the import iron ore accounts for 78.5% of all iron ore consumption. 82.5% of the import iron ore is from Australia and Brazil. To receive the huge volume of import iron ore from Australia and Brazil, many bulk ports or terminals have been constructed along the Yangtze River in recent years. Figure 1 shows the main ports along the Yangtze River.

Insert Figure 1 about here

Figure 1 Ports along the Yangtze River

Traditionally, the majority of iron ore is firstly transported to sea ports like Ningbo, Shanghai and Lianyungang by Capesize bulk ships from Australia and Brazil. Then, some of the iron ore is transshipped by Panamax or Handy bulk ships from these sea ports to the ports in the lower Yangtze River, for example, Nantong, Jiangyin and Nanjing. Finally, part of the iron ore is further transshipped to the middle and upper reaches of the Yangtze River by small river ships. In recent years, ports in lower Yangtze River are embracing more calls of mega ships, so a lot of large-scale bulk terminals have been built in these ports, in particular ports at the mouth of the Yangtze River. Table 1 shows the number of large-scale bulk terminals built in the ports at the mouth of the Yangtze River. It is noted that most ports have already had the capability to receive Capesize bulk ship or Capesize bulk ship less than half-loaded. As a consequence, more ocean Capesize bulk ships are now witnessed calling at river ports at the mouth of the Yangtze River and imported iron ore can be transshipped only once via these ports.

Table 1 Big Bulk Terminals in the Yangtze River Ports in 2013

Insert Table 1 about here

From 2014, as the domestic demand of steel began to decline with the slowdown of China's economic growth, the amount of iron ore imports started to decrease. To avoid the possible disorder and cut-throat competition among bulk terminals along the Yangtze River, both local authorities and industry are now seeking for a sustainable development plan to deal with the challenge facing by the ports. Under this background, this paper aims to analyze the development potential of the Yangtze River bulk ports system under different uncertainties.

This paper builds upon the literatures of port-geography and shipping network optimization. We firstly explicate the multi-layer bulk transshipment system in the Yangtze River and explain the transshipment patterns, and we build a mathematical model to optimize the transshipment volume distribution among the ports considering the unique geographic feature of Yangtze River and transshipment pattern. Using the model, several proposed scenarios are examined by changing corresponding parameters. Cooperation among ports as one scenario is analyzed by applying core theory in cooperative game. Based on the changes of transshipment volume distribution among ports observed under the various scenarios, we finally can ascertain the different development potential of the system, and provide suggestions to the port operators and local maritime authorities accordingly. This paper has two contributions to the previous literatures. Firstly, shipping network optimization literatures mainly focus on hub-and-spoke system of container ports, this paper attempts to study the multi-layer bulk transshipment system in inland river which has been rarely addressed by other literatures. Second, instead of conducting pure qualitative analysis as most of relevant literatures did, this paper conducts a sophisticated analysis of inland bulk transshipment system by employing both the optimization model and the economic model (core theory) together.

The following part of this paper is organized as follows. Section 2 reviews literatures with regard to inland shipping system analysis and design. Section 3 explicates the bulk transshipment system in the Yangtze River and describes the cases where we will apply the optimization model to. In section 4, we present the optimization model based on the cases introduced in section 3. Four scenarios concerning the current and future changes are tested in section 5, some suggestions are provided based on the implications from scenario analysis. Section 6 we draw the conclusion.

2. Literature Review

The development of inland port system falls within the port-geography literature. Notteboom (2007) discussed the similarities and dissimilarities between the development of container shipping network of the Yangtze River and the Rhine. He found Yangtze service network has the tendency to converge, in more than one aspect, with the development pattern of inland container services in the Rhine basin. Veenstra et al. (2008) investigated the bottlenecks confronting the container transport along the Yangtze River in a structured way. They concluded that there is no immediate capacity shortage in either ports or the fleet, and the current service networks are inefficient. Notteboom and Rodrigue (2005) proposed a general port-system evolution model. This model has been applied in studying the development of the Yangtze River shipping system. For example, Veenstra and Notteboom (2011) studied the level of cargo concentration and the degree of inequality in operations of the Yangtze River container ports by adopting the port development model. Wang and Ducruet (2012) further examined the impact of the emergence of Yangshan on the port development pattern of the Yangtze River Delta since the 1970s, also with reference to the port system evolutionary model. Although some interesting implications were presented in these studies, it is noted that most of these studies applied qualitative methods and only focused on container ports.

Researchers have broadly addressed the shipping route design and scheduling problem. As early as 1983, Ronen published a review paper on models and problems in the routing and scheduling of cargo ships. In the recent decade, Christiansen et al. (2004) and Meng et al. (2014) summarized the research development on this topic in succession. Moon et al. (2015) firstly presented an ocean tramp ship routing model of fleet deployment in a hub-and-spoke network by adopting a genetic algorithm. Compared to ocean shipping, the studies on river shipping network are limited. Charles (2008) explored the competitive navigational area of sea–river shipping for different ports on the Rhône-Saône corridor. Konings (2007) evaluated the improvement from reorganizing the container barge service in the hinterland of Rotterdam. Konings et al. (2013) furthermore examined the hub-and-spoke system in the seaport of Rotterdam, with the ultimate aim of improving container barge transport in the hinterland. Racunica and Wynter (2005), and Meng and Wang (2011) investigated the economies of scale in inland intermodal transportation. Frémont and Franc (2010), Wilmsmeier et al. (2011), and Caris et al. (2014) discussed intermodal freight transportation including inland shipping. Yang et al. (2014) applied the shipping route design method in studying container shipping network in the Yangtze River. They incorporated fleet deployment, port-calling frequency, and transshipment operations in their model. Zheng and Yang (2016) built a more practical tool and conducted empirical test to explore the economies of scale of the container ports system in the Yangtze River. They optimized the Yangtze River container shipping system as a hub-and-spoke network by implementing mixed-integer linear programming. These studies deal with the hub-and-spoke system of container shipping. Bulk shipping network in Yangtze River, which is a multi-layer transshipment system and the focus of our study, has been rarely addressed in the literature.

Game theory is regarded as one of the most effective tools for analyzing economic stability of competitive market. As the most important concept of cooperative game, core theory makes predictions of the relation between revenue/cost and feasibility of cooperation by modeling the interactions of economic decision-maker (Yang et al., 2011). The core theory has been broadly applied in economics stability analysis of shipping liner alliance (Song and Panayides 2002; Panayides and Wiedmer, 2010, Yang et al., 2011). As for port/terminal cooperation, Saeed and Larsen (2009) evaluated the different combinations of coalitions among the three terminals in Karachi Ports by applying Bertrand competition model and core theory. Core theory has also been applied together with optimization model, Agarwal and Ergun (2010) combines the optimization model and core theory as tool to design a mechanism to guide the carriers in an alliance to pursue an optimal collaborative strategy. These literatures implied that the core theory, together with optimization model, can be suitable to analyze the stability of port cooperation.

The contribution of this paper is two-folds. Firstly, this study focuses on the inland iron ore shipping network analysis which has been rarely addressed by other literatures before. It can be further extended to more cargoes types in inland shipping of other regions. Secondly, this study employs both optimization model and economic analysis (core theory) to achieve its research objective. The proposed methodology is capable of assisting the decision-makers to coordinate port resources under uncertain external changes.

3. Bulk Shipping System in the Yangtze River

As Figure 2 shows, Ningbo-Zhoushan, Shanghai and Lianyungang are three big sea ports close to the mouth of the Yangtze River. The majority of import iron ore from Australia and Brazil is traditionally firstly shipped to these ports by Capesize bulk ship (larger than 180,000 dwt) and then is transshipped to ports on the lower Yangtze River. Some of the iron ore is consumed in this region, and the rest is further transshipped to ports deep on the Yangtze River. Two modes of transshipment can be identified in the first transshipment stage. With the first mode, all the iron ore carried by Capesize bulk ship is discharged at one sea port and then uploaded to Panamax or Handy size ships to be carried to the ports on the lower Yangtze River. The second mode is called lightening transshipment, of which only half or two thirds of the iron ore is discharged at one sea port, the rest is still carried by the same Capesize ship to the ports on the lower Yangtze River.

Insert Figure 2 about here

Figure 2 The Multilayer Transshipment System of Bulk Port

Note: The black-filled area denotes the part of transshipment iron ore at a port
Source: Own realization based on Yearbook of China Transportation and Communication

The lower Yangtze River can be divided into three segments in term of the size of ships they can receive, as shown by the three dashed circles in Figure 2. (i) Suzhou port (including Zhangjiagang and Taicang) and Nantong port, located at the mouth of the Yangtze River, can receive super-Panamax size bulk ships (100,000 dwt). (ii) Jiangyin Port, the neighboring port of Suzhou and Nantong in the upper stream, is the last port which is capable of receiving 100,000 dwt ships but only when it is at high tide. (iii) Changzhou port, Taizhou port, Zhenjiang port and Nanjing port are located in the uppermost segment of the lower Yangtze River. The water depth of this segment is less than 12.5 meters, most reach is as deep as 10 meters, thus only 50,000 dwt bulk ship can sail into this segment. Now a dredging project is under way in this segment. This project is expected to be completed in 2019 when ports on this segment will be capable of receiving 70,000 dwt bulk ship.

Ports in the upstream of Nanjing, including Ma'anshan, Wuhu, Tongling, Jiujiang, Huangshi, Wuhan, Yueyang and Chongqing can only receive 5,000 dwt ships. In this study, we choose one port to represent all ports in the same segment. Specifically, we use Ningbo representing Shanghai, Ningbo-Zhoushan and Lianyungang, Nantong representing Nantong and Suzhou, Nanjing representing Changzhou, Taizhou, Zhenjiang and Nanjing, and Wuhan representing Ma'anshan, Wuhu, Tongling, Jiujiang, Huangshi, Wuhan, Yueyang and Chongqing. Demands of other ports in the same segment will be added to the representing port. The demand of iron ore for a certain port is basically all from the local steel plants, which are necessarily located closely to the port. This means for these ports the demand rarely overlaps across regions. Thus, this assumption can simplify the presentation model without loss of generality. With the ports chosen, the shipping routes of imported iron ore to Yangtze River can be summarized in Table 2. It is noted that both 50,000 and 70,000 dwt ships to Nanjing are considered in our model, so as to conduct a comparison.

Table 2 Shipping Routes of Imported Iron Ore to Yangtze River

Insert Table 2 about here

The first line in Table 2 presents that 200,000 ton Australia iron ore is carried to Ningbo by a 200,000 dwt Capesize ship firstly, then transshipped by two 100,000 dwt ships to Nantong. Some of the iron ore discharged in Nantong will be further transshipped to the ports deep on Yangtze River by 5,000 dwt river ships. Differ from the first line, in the second line, only 100,000 ton iron ore from a 200, 000 dwt Capesize ship is discharged in Ningbo, the rest 100,000 ton iron ore will be still carried by the same 200,000 dwt Capesize ship to Nantong and then some of them will be further transshipped by small ships to deep river. The 10th line means 70,000 ton Australia iron ore are carried by a 70,000 dwt Panamax size bulk ship to Nanjing directly and then is further transshipped to deep river by small ships.

Five types of bulk terminals are considered in our study, which are capable to receive ships of 5000, 50,000, 100,000, 200,000 and 300,000 dwt respectively. Note that small ships can berth in big terminals, but not the opposite.

4. The Model and Data Description

To build the model, we list the notation below.

Sets:

B	Set of types of berths; each type is defined by the largest ship it can accommodate; $B \coloneqq \{1,2,\ldots,\lvert B\rvert = 6\}$; we assume that a larger index represents a type of larger berth and here $b = 1, 2, 3, 4, 5, 6$ represents berths that can accommodate 5,000-ton ships, 10,000-ton ships, 50,000-ton ships, 100,000-ton ships, 200,000-ton ships, and 300,000-ton ships, respectively.
P^0	Set of source ports, $P^0 \coloneqq \{\text{Australia}, \text{Brazil}\}$
P	Set of ports in China, $P \coloneqq \{1 = \text{Ningbo}, 2 = \text{Nantong}, 3 = \text{Jiangyin}, 4 = \text{Nanjing}, 5 = \text{Wuhan}\}$
R	Set of all shipping routes

Parameters:

T	Number of available hours of a berth in a year, $T = 300\ \text{days/year} \cdot 24\text{h/day} = 7{,}200\text{h/year}$
n_{pb}	Number of berths of type $b \in B$ at port $p \in P$
q_{op}	Annual demand (1000 tons) from source port $o \in P^0$ to port $p \in P$
t_{rpb}	Number of hours for loading or unloading at berth type $b \in B$ of port $p \in P$ required by route $r \in R$; e.g., we only consider the unloading time required at Nantong for a route from Australia to Nantong; we consider the unloading time required at Ningbo and at Nantong for a route from Australia to Nantong but the ship lightened at Ningbo; and we consider the loading time

at Nantong and unloading time at Wuhan for a route from Nantong to Wuhan

c_r Unit cost of cargo (RMB/1000 tons) transported on route $r \in R$; it consists of the cost of the ships and the cost of loading and unloading

c'_{op} Penalty cost of unfulfilled demand (RMB/1000 tons) from source port $o \in P^0$ to port $p \in P$; c'_{op} is set at 500,000 for Ningbo, Nantong, Jiangyin, and Nanjing, and 1000,000 for Wuhan

w_{rop} Amount of cargo (1000 tons) transported on route $r \in R$ from source port $o \in P^0$ to port $p \in P$; w_{rop} is negative if the port $p \in P$ is the port of origin (e.g., Nantong is the port of origin for a route from Nantong to Wuhan)

Decision variables:

x_r Operation level of route $r \in R$, i.e., how many times the route is repeated per year (how many times per year the same ship load of iron ore is transported from the same origin port to the same destination port)

y_{op} Annual amount of demand from source port $o \in P^0$ to port $p \in P$ that is fulfilled

z_{op} Annual amount of demand from source port $o \in P^0$ to port $p \in P$ that is not fulfilled

θ_{pb} Annual hours required for loading or unloading at berth type $b \in B$ of port $p \in P$

With these notations, we can build the models as follows:

Mathematical model:

$$[\boldsymbol{M1}] \quad Minimize \quad \sum_{r \in R} c_r x_r + \sum_{o \in P^0} \sum_{p \in P} c'_{op} z_{op} \tag{1}$$

subject to:

$$y_{op} = \sum_{r \in R} w_{rop} x_r \qquad \forall o \in P^0, \forall p \in P \tag{2}$$

$$\theta_{pb} = \sum_{r \in R} t_{rpb} x_r \qquad \forall p \in P, b \in B \tag{3}$$

$$\sum_{b=b'}^{|B|} \theta_{pb} \leq T \sum_{b=b'}^{|B|} n_{pb} \qquad \forall p \in P, b' \in B \tag{4}$$

$$y_{op} + z_{op} \geq q_{op} \qquad \forall o \in P^0, \forall p \in P \tag{5}$$

$$x_r \geq 0 \qquad \forall r \in R \tag{6}$$

$$y_{op} \geq 0 \qquad \forall o \in P^0, p \in P \qquad (7)$$

$$z_{op} \geq 0 \qquad \forall o \in P^0, p \in P \qquad (8)$$

In the model $M1$, Objective (1) minimizes the sum of total transportation costs and penalty for not fulfilling all of the demand. Constraints (2) calculate the fulfilled demand. Constraints (3) calculate the required number of berth hours at each type of berth of each port. Constraints (4) impose limited berth resources at each port. Note that we use Constraints (4) rather than $\theta_{pb} \leq Tn_{pb}$ because a larger berth can be used to accommodate a smaller ship when there are not enough smaller berths but surplus larger berths. Constraints (5) calculate the unfulfilled demand. Constraints (6) to (8) define non-negativity of the decision variables.

The demand data is derived and sorted from the Yearbook of China Transportation and Communication (2014). It is noted that the origins of demand, namely Australia and Brazil, are not identified in the statistic book at the port level. But the ratio of iron ore from the two origins can be estimated based on the import amount at the national level. Thus, the origin of demand for a certain port is calculated based on the national level ratio.

The number of terminals in each port is collected from port homepages, Yearbook of Chinese Ports, and Zhang and Wang (2015). The available operating days of a berth is set to be 300 days per year. The unit cost, including shipping cost and loading and unloading cost, is obtained from the authors' investigation. The transshipment is more expensive than lightening transshipment because in the latter one time of loading and unloading is saved. The loading and unloading efficiency in every port is assumed to be the same, but the docking time is supposed to be different for ships of different size.

With regard to the future development potential of the Yangtze River bulk transshipment system, we propose four scenarios for analysis, which are summarized as follows:

a. The current dredging project is completed;

b. The total iron ore demand decreases by 20%;

c. Two new modern large-scale bulk berths are built in Nantong, Jiangyin or Nanjing respectively;

d. Port can choose to cooperate with other ports by adopting a proper pricing strategy, namely changing their port fees together.

5. Scenario Analysis

This section tests the four hypotheses listed in Section 4. Table 3 shows the optimized annual cargo volume assignment to each route under each scenario.

Table 3 Optimal Shipping Route in Different Scenarios (000 ton)

Insert Table 3 about here

5.1 Three basic analyses

It is noted, to satisfy the demand at the least cost under the current limitation, the iron ore from Australia is suggested to be transshipped via Nanjing and Jiangyin to the upper river, where 80% is via Nanjing. In the stage of ocean shipping, direct transportation to Nanjing by 50,000 dwt ship and lightening transportation via Ningbo to Jiangyin is recommended. For the iron ore from Brazil, the twice transshipment strategy, for example first to Ningbo by 300,000 dwt Capsize ships, then to Nanjing by 50,000 dwt river-sea ships, and finally to the destination ports in the upper river, is recommended. Nantong, Jiangyin and Nanjing almost averagely share the second transshipment cargo volume to the upper river. It is found that the transshipment pattern for Australia iron ore and Brazil iron ore is very different.

The 12.5m-deep shipping lane dredged shows insignificant influence on the change of shipping pattern, but the total shipping costs can be saved by 653,520 Chinese yuan per year after it is completed.

If the demand decreases by 20% in the future, in the optimal plan, more Australian iron ore is transshipped through Jiangyin to the upper river. At the same time, more Brazilian iron ore is transshipped via Ningbo to Nanjing and then to the upper river. There will be no Brazilian iron ore transshipped in either Nantong or Jiangyin in this case. This is because it is more efficient for bigger ships to carry cargoes as far as possible.

Two new berths built in Nantong or Jiangyin will lead to a significant rise of transshipment volume in these two ports, while the transshipment volume in Nanjing will decrease. In contrast, if two new berths are built in Nanjing, no change is observed in the transshipment volume distribution among these ports.

We can summarize some policy implications from the above analysis. First, the lightening transportation is the most economical way to import iron ore to the Yangtze River. It can be expected that more Capesize ships adopting the lightening strategy will sail into the lower Yangtze River in the future. This should be taken into consideration by local maritime authorities in standardizing the inland river ships and managing the inland navigational safety given the complexity of inland waterways. Second, the 12.5m-deep shipping lane dredged shows insignificant influence on the change of shipping network, but can save the cost of carriers in total. Third, Jiangyin and Nanjing, located at the junction points of segments with different depths of water at the lower Yangtze River, have strategic advantage for the transshipment of iron ore to the upper river, in particular when the demand decreases. Fourth, ports at the mouth of the Yangtze River should consider reforming old terminals or building new ones to receive large ships which can help them to increase the transshipment volume.

5.2 Cooperative stability analysis in the game framework

Various coalitions can be formed among the three ports of Nantong (NT), Jiangyin (JY) and Nanjing (NJ). Raising or reducing the price together is one strategy they can choose to adopt.

Then, this becomes a case of three ports cooperative game. Simply, we want a notion of a priori evaluation of a coalitional game by each of its players (the ports). The core in cooperative game theory is usually given as "standards of behavior" for testing the stability of the coalition. The details can be found in Owen (2013). Simply, for an arbitrary TU (transferable utility) game (N, v), where N is a finite or a countable player set and v is a map assigning to each $S \subset N$ a real number and $v(\phi) = 0$, any n-tuple payoff vector x_i of a game (N, v) satisfies

1. $\sum_{i \in S} x_i \geq v(S),\ S \subset N$ (Individual rationality) and, (9)

2. $\sum_{i \in N} x_i = v(N)$ (Collective rationality) (10)

are named imputation. The individual rationality and the collective rationality together guarantee that no players in a cooperation scheme have anything to gain by changing only their own strategy. The imputation can be thought as a possible profit arrangement that satisfies minimal conditions of rationality. The set of imputations satisfying the conditions of the coalition rationality constitutes the core, in another word, the coalition is stable. In the context of ports game in this study, the N is {NT, JY, NJ} and S include {NT, JY, NJ}, {NT, JY}, {NJ, JY}, {NJ, NT}, {NJ}, {NT}, {JY}. The map v means the payoff of port when it cooperates with other ports in arbitrary sub-coalition S by raising or reducing port fee together. Naturally the change of ports fee may lead to the change of market share. Mathematically, the payoff of port i is represented

$$v(i) = c'd'(i) - cd(i) \tag{11}$$

where *c'* and *c* denote the port fee after cooperation and before cooperation at port *i*, respectively, and *d'*(*i*) and *d*(*i*) denote the annual cargo handling amount after cooperation and before cooperation at port *i*, respectively.

Table 4 and Table 5 list the calculated payoffs of the three ports in various combination of coalitions. Two price changing strategies are pre-set in this study. One is 25% increase and the other 25% decrease.

Table 4 Payoffs of Ports in Various Forms of Sub-coalition (25% Price Up)

Insert Table 4 about here

Note: the number in the bracket denotes the change of transshipment cargo volume

Table 5 Payoffs of Ports in Various Forms of Sub-coalition (25% Price Down)

Insert Table 5 about here

Note: the number in the bracket denotes the change of transshipment cargo volume

It can be observed that when "raising the port fee" strategy is adopted by any Nanjing-included coalition, namely {NT, JY, NJ}, {NJ, JY}, {NJ, NT}, the transshipment cargo volume of Nantong and Jiangyin will remain unchanged, but the volume of Nanjing will decrease by 9%. For any coalitions without Nanjing, eg., {NT, JY}, {NJ}, {NT}, {JY}, at least one port will lose more than 25% transshipment cargo volume, which leads to a deficit of income. Based on equation (9) and (10), only coalitions including Nanjing are stable when the "raising port fee" strategy is adopted. Still according to equation (9) and (10), it can be reckoned that this stability may change if the port fees increase to the point where the total market share taken by Ningbo from three ports is equal to the increasing ratio of the port fee, which is 25% in our case. When "reducing the port fee" strategy is adopted, the payoffs of the ports can be shown in Table 5. It is noted there will be no coalition in which all ports can achieve more than what they earn now. Thus, the core is empty and no stable cooperation exists.

These findings indicate when Nanjing raises its port fees by 25%, Nantong and Jiangyin have the chance to raise their port fees at the same level without losing transshipment market shares. Nanjing will lose its transshipment market share. However, Nanjing will earn more profits because the increment of port fees is higher than the loss of transshipment market share. Reducing price is not a feasible strategy for all ports in any cooperative schemes.

6. Conclusion

In the past decades, a multilayer transshipment network of bulk shipping has been formed along the Yangtze River so as to support the fast development of Chinese iron and steel industry. With the decrease of iron ore trade volume in China since 2014, the bulk port system of Yangtze River will be subject to significant changes in the future. Under this background, this paper aims to analyze the development potential of the Yangtze River bulk ports system by testing various scenarios. The optimization model and core theory in cooperative game are applied to achieve the objective.

Based on the analyses presented in this paper, we find the lightening shipping is the most economical way to ship the import iron ore into the Yangtze River, and thus has great opportunities for development. Local maritime authorities should take the lightening shipping into consideration in the standardization of inland river ships and also the management of inland navigation safety. The ports at the mouth of Yangtze River should think about reforming existing bulk terminals or building new bulk terminals to embrace more half-loaded Capesize ships to berth. Jiangyin and Nanjing have strategic advantage for the transshipment of iron ore to the upper Yangtze river thank to their geographic locations. The advantage becomes more significant if the iron ore demand decreases. Nanjing has the decisive advantage in setting up a coalition by adopting “raising the port fees” strategy. That is, only a coalition including Nanjing is recognized as stable coalition in implementing this strategy.

This topic can be further developed in two ways. First, more cooperative strategies and larger cooperative scope can be taken into consideration, for example, ports in the same coalition can share their terminals, and ports on the lower Yangtze River can cooperate with nearby seaports. Second, as some terminals can handle both iron ore and coal, the impact of coal transshipment can also be added in the future study. The limitation of the model is the assumption of some input data, for example, the average number of available days of a berth in a year. If the uncertainty of the data must be captured when dealing with a tactical or operational problem, then stochastic programming approaches should be taken into consideration in the future.

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