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Research Article

Game-Theoretic Comparison Approach for Intercontinental Container Transportation: A Case between China and Europe with the B&R Initiative

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This paper develops a game-theoretic model to analyze the competition between two container freight transportation modes (shipping and railway) using competitive game strategic interactions method, namely, deterrence, by taking account of the most cost-effective scale of the transportation capacity settings. The competition was set against the background of China's Belt and Road (B&R) Initiative as a new situation for intercontinental Sino-Europe container freight transportation. The behavior of each mode (modeled as a carrier, resp.) is characterized by an optimization model with the objective of minimizing its cost by setting optimal basic freight rate and transportation deployment. A firm can use this method to compare the difference in the time value of the cargos and reduce the expense during the whole transportation process. Finally, the developed model is numerically evaluated by a case study of intercontinental transportation between Hefei (China) and Hamburg (Germany). The results show that deterrence effects largely depend on the deterrence objective, and the differential in the cost of two transportation modes tends to be stable with higher values in the deterrence objective. In the new intercontinental circumstance, the mode of railway transportation provides a new way to transport the cargos between China and Europe.

1. Introduction

In recent years, shippers with regular transport demands (e.g., manufacturing enterprise and sales companies) are always eager to minimize their transportation cost in the process. They always endeavor to select the optimal transport mode and perfect route to minimize the cost and time in the transportation process.

From another perspective, global liner container shipping companies seek new emerging container shipping markets to maximize their profit margins while intercontinental trade and attendant transportation demands among China, Central-Asia, Russia, and Europe continue to grow steadily. For example, several liner container shipping companies including APL (http://www.apl.com) and PIL (https://www.pilship.com) have provided regular shipping service between Shanghai Port (China) and Hamburg Port (Germany) recently, and they competed on basic freight rate and shipping deployment (a combination of frequency and ship capacity setting). Furthermore, several block trains from China to Central-Asia, Russia, or Europe have added new transportation mode that forged commercial container freight movements among the regions, since the first Sino-Europe block train (officially named as "CHINA RAILWAY Express" and abbreviated as "CR express") started its first trip at Chongqing (China) in 2011. However, this newer train transportation operates at higher basic freight rates and lower frequency than shipping and provides opportunity for service optimization and improvement.

In essence, this study focuses on the competition of container freight movements, mainly from the shippers' perspectives by setting the objective of how one can transport the container cargo in a comparatively economic (both time and money) way. In context, the following questions are raised:

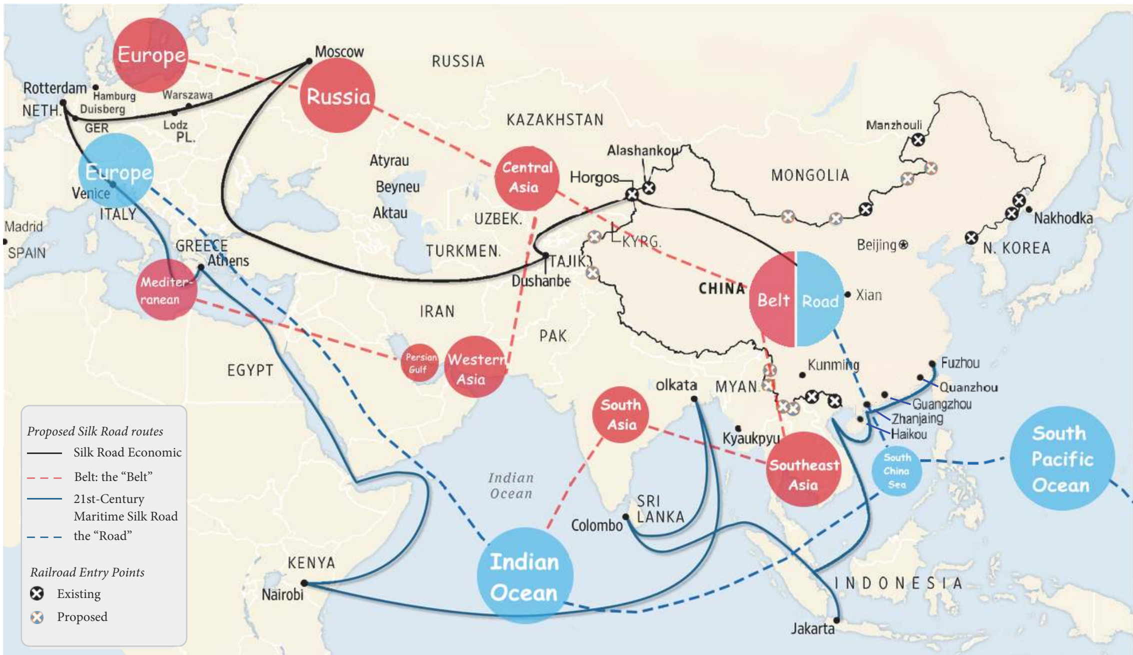

Figure 1: The Routes of "the Silk Road Economic Belt and the 21st Century Maritime Silk Road" (source: author, adapted from http://www.xinhuanet.com/; https://www.wsj.com/; and http://www.un.org/).

(1) What are the aspects one should consider when choosing a mode of transportation to transport containerized cargo to another continent, especially between China and Europe with the background of the Belt and Road (B&R) Initiative that offers a new mode of choice?

(2) If the two modes of transportation (shipping and railway) compete with each other, using the deterrence game theory, which will win in the competition?

The primary thrusts of the study are as follows: (1) firstly, the B&R Initiative is introduced with both land and maritime routes. Meanwhile, the main CR expresses and the trading volume from China to Hamburg (which is one of the most important ports in Europe) are demonstrated; (2) secondly, the two aspects that shippers (firms) care most, namely, time and cost, are illustrated in the study, in which time value consideration in the cost function makes the overall cost more comparable; and (3) finally, the game-theoretic model is developed from the perspectives of the shippers. In addition, the application of the deterrence model (route from Hefei to Hamburg) is proposed.

The paper is organized as follows. After this introductory section, the background and literature review are presented. The following section proposes the methodology applied and developed in this research, including the problem description, the notations, assumptions and formulas related to the model, the entry-deterrence game models, and the algorithm. Furthermore, a cased study is presented with the findings. The final section gives the conclusions as well as further discussion of the study.

2. Background and Literature Review

2.1. The Belt and Road Initiative. The Chinese government has in recent years embarked on a major plan in building better linkages (especially transportation connection) between Europe and Asia by way of "the Belt and Road (B&R) Initiative" (also known as "One Belt One Road" or OBOR). OBOR is essentially a Chinese framework for organizing multinational economic developments through two component plans, the land-based "Silk Road Economic Belt" (SREB) and ocean-going "Maritime Silk Road" (MSR), as is shown in Figure 1. The Belt and Road, a reference to the Silk Road Economic Belt and the 21st Century Maritime Silk Road, was initialized by Chinese President Xi Jinping during his visit to Central-Asia and Southeast Asia in September and October 2013, which also called for accelerating Belt and Road construction in the government work report of China in March 2015. It offers a great opportunity for intercontinental logistics companies, which shall engender support by the governments of many countries in Asia, Africa, and Europe.

Several CR expresses have been set up to support the implementation of the SREB and to meet the requirements of the rapid growth of trade between China and Europe. As is shown in Table 1, there are basically two regions of transit hubs, which are located in Xinjiang and northeast part of China. Until December 2016, there are more than fifteen CR expresses from China to Europe originating within China; the majority are going out of China through Alashankou (Xinjiang) rather than through Manzhouli (Heilongjiang) and Erenhot (Inner Mongolia). As showed in Tables 1–3, route distances between the origins and destinations vary from 8,027 to 13,052 km, and most journey durations are around 15 days. The earliest Sino-Europe block train "Yuxinou" (from Chongqing to Duisburg, now all use CR express as a brand) has been in operation for more than 6 years and is an important part of the cargo transportation network to Europe

Table 1: Major "CR expresses" (via Xinjiang (Alashankou hub)) (source: author, adapted from [1] and news from https://www.yidaiyilu.gov.cn/).

Origin	Destination	Route distance (km)	First start date	Journey duration (days)	Direction
Chongqing	Duisburg (Germany)	11,179	Mar 19, 2011	13	Two-way
Chengdu	Lodz (Poland)	9,965	Apr 26, 2013	14	Two-way
Zhengzhou	Hamburg (Germany)	10,245	Jul 18, 2013	15	Two-way
Wuhan	Pardubice (Czech)	10,863	Apr 24, 2014	15	Two-way
Yiwu	Madrid (Spain)	13,052	Nov 18, 2014	21	Two-way
Lanzhou	Hamburg (Germany)	8,027	Aug 21, 2015	15	Two-way
Hefei	Hamburg (Germany)	11,000	Jun 26, 2015	15	One-way
Wuhan	Hamburg-Duisburg (Germany)	Ca.11,000	Jan 1, 2016	15	Two-way

Table 2: Major "CR expresses" (via Manzhouli hub) (source: author, adapted from [1] and news from https://www.yidaiyilu.gov.cn/).

Origin	Destination	Route distance (km)	First start date	Journey duration (days)	Direction
Chongqing	Cherkessk (Russia)	10,000	Nov 11, 2014	14	One-way
Tomsk (Russia)	Wuhan	9,755	Nov 2014	13	One-way
Suzhou	Warszawa (Poland)	11,200	Sep 29, 2013	15	One-way
Brest (Belarus)	Suzhou	Ca. 10,000	Sep 29, 2013	13	One-way
Shenyang	Hamburg (Germany)	11,000	Nov 30, 2015	12–14	Two-way
Yingkou	Zabaikalsky (Russia)	6,500	Apr 9, 2016	10	Two-way

Table 3: Major "CR expresses" (via Erenhot hub) (source: author, adapted from [1] and news from https://www.yidaiyilu.gov.cn/).

Origin	Destination	Route distance (km)	First start date	Journey duration (days)	Direction
Zhengzhou	Hamburg (Germany)	10,399	Dec 3, 2013	15	Two-way

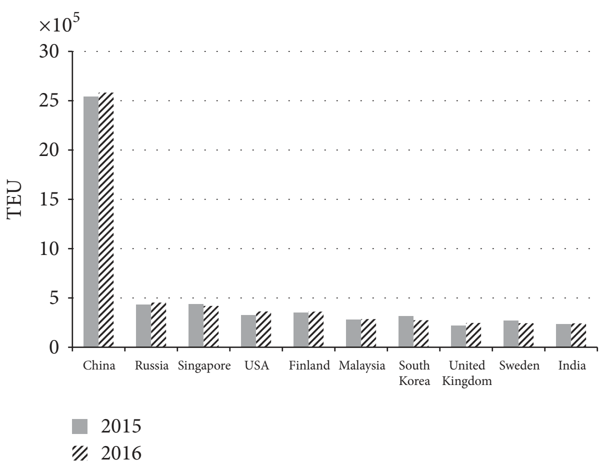

Figure 2: Top 10 trading partners in seaborne container traffic of Hamburg Port (source: author, adapted from https://www.hafen-hamburg.de/).

in Southwest China. Some CR expresses that are collecting cargos from almost the same regions compete with each other with shorter running time and lower freight rate. The number of CR expresses (from China to Europe and to Central-Asia) has grown to twenty-one trains in total by December 2016, and it is projected to soon expand further to twenty-six trains in total.

As illustrated in Figure 2, China commands the largest volume in seaborne container traffic as a trading partner with the Hamburg Port, at above 2,500,000 TEUs in 2015 and 2016. In this paper, trading partner is one of the two or more participants in an ongoing business relationship. With the large trading volume and the huge potential market, there is naturally huge transportation competition among the carriers and modes (shipping, railway, and airline). With Hamburg as a dominant European hub, container throughput with Chinese ports made good progress, increasing by 1.6 percent from 2015 to reach 2.6 million TEUs in 2016. To be more specific, the volume in Figure 2 covers containers that are transported from different origins to the Hamburg Port, as well as containers transported from Hamburg Port to different destinations.

2.2. Literature Review. With the background of B&R Initiative, if a firm (shipper) wants to transport its cargos between China and Europe, usually there are three modes, which are shipping, railway, and airline. For container transportation, airline is much more expensive than the other two modes and is also smaller in capacity; hence, airline mode is not considered in this study. Therefore, this research focuses on comparing the transportation modes between shipping and railway. To study this issue, it is essential to have knowledge and findings of to-date research studies. Hence, existing literatures are reviewed in the following parts about the international trade between China and Europe under B&R Initiative, the competition in relative research ranges, and the applications of game theory in transportation.

Although the world economy is experiencing a period of slow-moving recovery, global seaborne transport is still an important way to move the world merchandise trade [2]. In line with the increase in international business and trade, there has been growing interest in improving transportation connection between Asia and Europe. Fallon [3] studied political, economic, and ideological differences between Silk Route Initiatives proposed by different countries and organizations and believed that the B&R Initiative positively influences the world development and wealth. Hilletofth et al. [4] examined Eurasia as a land bridge for container traffic and applied the Finnish case to show the lead time advantage of the railway for a manufacturer, but there are hindrances for railway transport that need to be overcome. Panova [5] considered the B&R Initiative as a new modern transcontinental transportation system and stated that the corresponding level of service is in high demand between China and Europe with the growing market integration and globalization. Hanaoka and Regmi [6] studied the status of intermodal freight transport in Asia from the environmental perspective. In addition, Mo et al. [7] discussed the economically suitable areas of China's transnational container transport by land (rail or road) in the B&R Initiative. Wang [8] analyzed the situation on the development of Sino-Europe block trains (which are now CR expresses) based on the aspects of market demand, transport organization, and operation and proposed several suggestions on how to deal with the existing problems. Wang et al. [9] carried out a survey about the transport condition, urban transport development, and the new mode of the international trade to analyze the industry structure status and proposed suggestions on the economic development of Xi'an (a city in China) under the B&R Initiative.

Freight transportation is usually carried out through road, railway, airline, or shipping. The research on the selection of the transport mode is always a key focus. Different transport modes have different characteristics regarding the time, cost, and capacity. Peyrouse and Raballand [10] indicated that the selection of the transport modes is mainly dependent on time, service, and price. Rich et al. [11] described the estimation of a weighted discrete choice model which is applicable for selecting the proper transport mode. According to Wang and Yeo [12], the transport modes differ in level of reliability, safety, and capability. Luo and Chen [13] stated that a shipper makes decision on which transportation mode to choose based on subjective reasons and experience. Álvarez-SanJaime et al. [14] compared the freight transport between the road and maritime sectors.

Competitions within one transport mode are also studied by many researchers. Lee et al. [15] presented a novel multilevel hierarchical approach which modeled the oligopolistic and competitive behavior of carriers and their relationships in maritime freight transportation networks. Hao [16] proposed a framework in order to analyze the container port competition and the feasibility of hub port implementation in China. What is more, in the process of the intermodal transportation, Wang and Zhu [17] focused on the optimization within the railway container terminal to shorten the transport time. Moreover, some researchers studied entry-deterrence for a single transport mode. Lin [18] investigated the role of code-sharing alliances on entry-deterrence, with one major carrier that operated a network and one potential entrant of the domestics spokes and demonstrated that the major carrier's profits may vary according to the network size and its degree of product differentiation. Aguirregabiria and Ho [19] presented an empirical dynamic game of airline network competition which incorporated this entry-deterrence motive for using hub-and-spoke networks.

The application of game theory in traffic and transportation analysis has attracted increasing attention by the researchers. Fisk [20] presented two game theory models (Nash noncooperative and Stackelberg games) applied in transportation system modeling. Bell [21] envisaged a two-player noncooperative game to establish the performance reliability of a transport network as an important practical problem for engineers and planners involved in network design. Ishii et al. [22] constructed a noncooperative game-theoretic model where each port selects port charges strategically in the timing of port capacity investment and examined the effect of interport competition between two ports. The game theory model also had been applied in many other areas like supply chain management, traffic route choice behavior, traffic routing, and so on (Leng and Parlar [23]; Qi et al. [24]; Jiang et al. [25]).

The game-theoretic model is regarded as one of the most effective approaches to analyze the competitive behaviors for liner shipping [14]. Song and Panayides [26] applied two-player cooperative game theory to analyze the interdynamics of liner shipping strategic alliances involving interorganizational relationships. Min and Guo [27] developed a cooperative game-theoretic model to determine the optimal location of hub-seaports and then harmonize the port links in a global supply chain network. Imai et al. [28] analyzed the economic viability of deploying container megaships based on the game theory by applying a nonzero sum, two-person game to obtain the optimal shipping service strategies in competitive shipping environments. Liu et al. [29] used cooperative game theory to analyze potential impacts of the Panama Canal expansion on the evolving competitive-cooperative relationships and the distribution of market power among the supply chain players in the US container-import market. Park and Min [30] analyzed fiercely competitive shipping markets in the Asia-Pacific region based on the noncooperative game theory and revealed that the container carrier's optimal shipping strategy was insensitive to changes in freight rates, fuel prices, and loading/unloading fees at the destination ports. Wang et al. [31] developed three game-theoretic models (Nash game, Stackelberg game, and deterrence) to analyze shipping competition between two carriers in a new emerging liner container shipping market. The results showed that the deterrence effects largely depend on the deterrence objective, an aggressive deterrence strategy may make potential monopolist suffer large benefit loss, and an easing strategy has little deterrence effect.

3. Methodology

3.1. Problem Description. According to the starting time and the capacity, the shipping liners start (back to hundred years ago or in 1975 when China reestablished diplomatic relation with European Union) much earlier than the railway

Table 4: Advantages and disadvantages of different modes of transportation (source: author).

Transport mode	Advantage	Disadvantage
Airline	Very fast, safe	Very expensive
Shipping	Cheap	Slow, humid
Traditional railway	Cheap	Slow, inconvenient
CR express	Fast, convenient, safe	Expensive

transportation (started in 2011) and with larger capacity, which means the shipping mode is more advanced and mature than the railway mode between China and Europe.

In this paper, we assume the scope of the entry-deterrence model can be enlarged into the container shipping services competition between two different modes of transportation from port A to port B. As a powerful economic tool, deterrence strategy has been introduced for quite a few service markets, including the transportation freight industries (Wang et al. [31]). By providing lower price to attract as many customers as possible, the incumbents typically prevent new entrants (Shi and Voß [32]). However, economists have some doubts on the effect of lower price deterrence. The entry-deterrence model has the advantage of using the competition method other than the normal selection method; thus one can differentiate from the perspective of the problem as existing studies. The results can more readily indicate which carrier or transport mode is competitive. However, by using the entry-deterrence model, competitors' freight rate scope has to be reasonable and comparative which may constrain the setting of the capacity and basic freight rate in the research.

This study aims to formulate an entry-deterrence model on the premise that the scope of the model can be enlarged into the container shipping services competition between two different modes of transportation involving liner (CR expresses and shipping liners) container movement from port A to port B. It is also important to note that though shipping liners may differ from one another, compared to railway operators, shipping liners do possess many characteristics in common among themselves. Therefore, with the upper and lower freight rate bounds, the shipping liners can be treated as one category of carrier in our study.

In freight transportation, the properties of the provided services affect the choice of both the mode of transportation and the specific carrier. Transport cost and transport time (including navigation time at sea and waiting time at the port) are regarded as two most prominent properties that affect the service choice decision-making, which also constitute the main considerations for the comparison analysis in this study. Without loss of generality, we assume transportation monetary cost and time cost as the two key costs.

Generally, each transportation mode has its own advantages and disadvantages. For example, the advantage of airline is fast speed, while its disadvantage is very expensive cost. In Table 4, the airline ranks the first in time-saving; however it is far more expensive than other modes. Shipping and traditional railway are quite cheap in price; however, the safety of the cargos cannot be ensured, the damage of cargos is more than other modes, and they have the longest transport time. The CR express is more expensive than shipping and traditional railway; however it is much cheaper than air (one-third of airline rate) and much faster (only half to one-third of shipping rate) than shipping mode.

3.2. Notations, Assumption, and Modeling Process. Consider a shipper that is interested in delivering the cargos between different continents. There are two alternative modes of freight transportation: shipping and railway. Each mode of transportation has several carriers and several lines. However, in order to make the problem easier to describe, here we suppose that each of the two modes has one carrier, namely, carrier 1 and carrier 2, which represent the mode of shipping and railway, respectively. For the purpose of this study, "carrier" not only refers to the carrier in maritime transportation but is also generalized as a carrier of the railway (which is normally called "train" in order to simplify the model). At the same time, carrier 1 here stands for the shipping liners of one category (since the shipping liners share many common characteristics) within the upper and lower bounds, so that carrier 1 is comparable with carrier 2 (railway operator).

In this paper, we use FEU (Forty-foot Equivalent Unit) as the measurement unit of a container. From the viewpoint of the shippers, if a shipper (usually a manufacturer or a trading company) wants the transport service between ports (or hubs) provided by carrier i $(i = 1, 2)$, it can be indicated by three main variables in the model, namely, freight rate, service frequency, and shipment capacity, according to the maritime container liners, where the following is found.

r_i is the freight rate of transporting per FEU for carrier i $(i = 1, 2)$, which differs among the carriers.

f_i is the service frequency offered by carrier i $(i = 1, 2)$, which presents the number of carriers calling from port (or hub) A to B in one week.

c_i indicates the shipment capacity setting for carrier i $(i = 1, 2)$, which is calculated in FEU in this paper as default.

First, we formulate the model of time. It is assumed that the container cargo delivery time follows a uniform distribution during each periodic service time window (from the departure time in previous week/month to the departure time in current week/month). Since the frequency of CR expresses is sometimes measured with the unit of month, so we propose two ways to estimate the relation between frequency and waiting time. As a result, the average waiting time for a container to be delivered by carrier i $(i = 1, 2)$ can be estimated by

$$T^W(f_i) = \frac{1}{2f_i} \tag{1}$$

in which $T^W(f_i)$ refers to the average time for a container waiting for the transport service offered by carrier i $(i = 1, 2)$.

$$T^W\left(f_i'\right) = \frac{1}{2f_i'} \cdot \frac{7}{30}. \quad (2)$$

Equation (2) presents the situation where f_i' refers to service frequency per month; besides, it is same as (1). In addition to the above two elemental factors (i.e., basic freight rate and navigation time), some other important influential factors cannot be underemphasized, including interport terminal handling charge (THC) and service-related attributes. So we consider the total time of the freight transportation, given by

$$T_i = \min\left\{T_i^S + T^W\left(f_i\right) + T_i^H\right\}, \quad (3)$$

where T_i^S is travel time from A to B for carrier i ($i = 1, 2$) and T_i^H is the container handling time at the port A or B for carrier i ($i = 1, 2$).

According to Tavasszy et al. [33] and Ravibabu [34], in the service choice decision-making, freight rate and transport time are regarded as two properties of great importance, in which the transport time includes navigation time and its hub waiting time.

Besides, some other factors also occupy important positions in freight transportation, such as THC (interport terminal handling charge) and factors which are attributed to the service indicators. These factors should not be overlooked since the heterogeneity of THC affects the market share for two carriers in a market according to Anderson et al. [35], even if it is of great difficulty to quantify the impact. Then, the generalized cost function of one FEU can be given as follows:

$$G\left(r_i, f_i\right) = \alpha\left[T_i^S + T^W\left(f_i\right)\right] + r_i + \beta \cdot \lambda_i + g\left(\nu_i\right) \quad (4)$$

in which α is the value of time, used as the additional amount of money that the shippers are willing to pay in order to shorten the transport time; β is the parameter used in the disutility function, for converting reputation into money cost; λ_i presents a score to reflect the reputation of carrier i ($i = 1, 2$), measured from 0 to 10; T_i^S presents the transport time from port (or hub) A to port B for carrier i ($i = 1, 2$).

According to Oppenheim [36] and Wang et al. [31], α and β should be calculated using practical historical data. In addition, this function includes four parts: cost measured by the transport time, transport (by rail or sea) cost in route, cost representing the reputation, and cost reflecting service level, respectively.

As part of the equation, we consider the level of service in terms of THC for each carrier. The function of the level of service offered by carrier i ($i = 1, 2$) is

$$g\left(\nu_i\right) = a_1 \cdot \nu_i + a_2, \quad (5)$$

where a_1 and a_2 are two positive coefficients determined by the real market. To be noted, we assume that the level service at the terminal is positively related to the unit container handling charge, which means that the higher THC reflects the better service level. As is shown in (5), it is a linear function to measure the level of service in terms of THC, ν_i for each carrier i ($i = 1, 2$). The generalized cost equation (see (6)) measures the utility with the length of time, the freight rate, and the service quality; however, pragmatically, there are also some factors, for instance, the congestions that exist in the terminal or service tracking and other immeasurable or unheeded factors not defined. However, the utility theory proposed by Ben-Akiva and Lerman [37] offers us a random utility for decision-making, which we take to reflect the attractiveness of transport service of a certain carrier. The equation is as follows:

$$U_i = -G\left(r_i, f_i\right) + \varepsilon_i, \quad i = 1, 2 \quad (6)$$

in which ε_i is assumed to follow Gumbel distribution. We use this logit-based discrete choice model to evaluate the market share for each carrier, since it is tractable and has a closed-form expression of the market share determination, which will facilitate the property exploration and application of the model.

In addition, an elastic demand function is introduced in terms of the expected maximum utility, which is also a vital issue in the market share determination. Therefore, the expected value of the maximum of two utilities U_1 and U_2 can be calculated by

$$\begin{aligned} &E\left[\max\left(U_1, U_2\right)\right] \\ &= -\frac{1}{\theta}\ln\left[\exp\left(-\theta \cdot G\left(r_1, f_1\right)\right) + \exp\left(-\theta \cdot G\left(r_2, f_2\right)\right)\right] \end{aligned} \quad (7)$$

in which θ is the dispersion parameter used to measure the degree of customers' perception errors on the utility. What is more, since the freight rate (per FEU) from one continent to another is usually more than a thousand dollars, when the expected maximum utility $E[\max(U_1, U_2)]$ is calculated, the parameter θ should be comparatively small. We take the following container transport demand functions as

$$d = d_p \exp\left(-\eta \cdot E\left[\max\left(U_1, U_2\right)\right]\right) \quad (8)$$

in which d presents the actual weekly container shipment demand from port A to port B, d_p is the potential weekly container demand from port A to B, and η is the elastic parameter predicting sensitivity of demand related to the utility. In this section, the demand function we chose is from the road freight transportation demand analysis and shipping liner competition, and there are also some other demand functions not mentioned. The probability of choosing carrier i ($i = 1, 2$) can be denoted as p_i ($i = 1, 2$) and it can also be considered as the container transportation market share for carrier i ($i = 1, 2$), which is expressed as

$$p_i = \frac{\exp\left(-\theta \cdot G\left(r_i, f_i\right)\right)}{\sum_{i=1}^{2}\exp\left(-\theta \cdot G\left(r_i, f_i\right)\right)}. \quad (9)$$

And d_i presents the weekly number of the containers transported by carrier i ($i = 1, 2$) and can be calculated by

$$d_i = d \cdot p_i = d \cdot \frac{\exp\left(-\theta \cdot G\left(r_i, f_i\right)\right)}{\sum_{i=1}^{2}\exp\left(-\theta \cdot G\left(r_i, f_i\right)\right)}. \quad (10)$$

In fact, the market share is decided by the shippers (or say as cargo owners) who are willing to spend less cost and expecting to have shorter transportation time at the same time. No matter how much market share each carrier can take, the shippers always aim to minimize the net costs for transporting containers from port A to port B.

According to Notteboom and Vernimmen [38], the transportation cost mainly includes total shipping cost, total container cargo handling cost at the terminal, and ship capital cost. Hence, regardless of the sunk cost of the conveyance (which is also presented as ship or railway capital cost), we assume that the full freight rates (namely, total transportation cost) paid by shippers are calculated from the basic rates plus the surcharges added by the carrier (together with ports or hubs) to its customers, including two main parts.

(1) Basic Freight Cost F_i^{BC}. The basic freight cost is the basic cost of transporting containers from port A to port B for carrier i ($i = 1, 2$), which means only considering the process in transit from port to port, while the surcharge fees and the relevant fees and charges within the ports or hubs are excluded. And the basic freight cost $F_i^{\mathrm{BC}}(f_i, c_i)$ can be calculated by

$$F_i^{\mathrm{BC}}(f_i, c_i) = \min\{d_i, C_i\} \cdot r_i = \min\{d_i, f_i \times c_i\} \cdot r_i \quad (11)$$

in which C_i refers to the weekly transportation capacity of the carrier i ($i = 1, 2$) and presented by $C_i = f_i \times c_i$ (FEUs/week). Moreover, $\min\{d_i, f_i \times c_i\}$ indicates the actual quantity of the shipped containers.

(2) Total Surcharges Cost F_i^{SC}. The total surcharges cost of the transportation includes two parts, which are the total container handling cost at the terminal (THC) (denoted as F_i^{HC}) and the other surcharges excluding the THC (i.e., bunker cost, container usage cost, and port or hub entry charge, denoted as F_i^{OC}). Therefore, we assume that the total surcharge can be calculated by

$$F_i^{\mathrm{SC}}(f_i, c_i) = F_i^{\mathrm{OC}}(f_i, c_i) + F_i^{\mathrm{HC}}(f_i, c_i) \quad (12)$$

in which the total surcharge cost is the result of total handling charge plus the other surcharges in light of its definition.

① *Total Handling Cost F_i^{HC}.* The reason for taking THC as an individual part in this session is that the THC has been considered as the biggest and most mature parameter to evaluate the cost for shippers to pay. To be more specific, two sets of THC are charged, and they are considered unchangeable over time in the time cycle, which are for port loading and port discharge according to Slack and Gouvernal [39]. The total container handling cost can be calculated by

$$F_i^{\mathrm{HC}}(f_i, c_i) = \min\{d_i, C_i\} \cdot \nu_i = \min\{d_i, f_i \times c_i\} \cdot \nu_i \quad (13)$$

in which $\min\{d_i, f_i \times c_i\}$ indicates the actual quantity of the shipped containers as mentioned above (in (11)), and the parameter ν_i shows the unit container handling cost for carrier i ($i = 1, 2$), which contains the THCs in the origin and destination ports or hubs.

② *Other Surcharges F_i^{OC}.* F_i^{OC} is the surcharge fees excluding THC (e.g., bunker cost, container usage cost, and port or hub entry charge) for carrier i, which can be defined as

$$F_i^{\mathrm{OC}}(f_i, c_i) = R_i \cdot C_i = R_i \cdot f_i \times c_i, \quad (14)$$

and R_i is surcharge fees excluding THC for carrier i ($i = 1, 2$) per container, which is per FEU in this paper.

Consequently, the total transportation cost F_i^C for carrier i ($i = 1, 2$) can be written as follows:

$$F_i^C = F_i^{\mathrm{BC}}(f_i, c_i) + F_i^{\mathrm{SC}}(f_i, c_i) \quad (15)$$

in which F_i^C, the total transportation cost for carrier i ($i = 1, 2$), includes two parts which are the basic freight cost F_i^{BC} and the total surcharges F_i^{SC}.

3.3. Model Description. Based on the above process analysis of the deterrence game-theoretic competition between the shipping and railway, we can obtain the total cost for a shipper to choose a specific shipping mode (considered as a carrier). The mathematical optimization model for the entrant is

$$\begin{aligned} F_i^C &= F_i^{\mathrm{BC}}(f_i, c_i) + F_i^{\mathrm{OC}}(f_i, c_i) + F_i^{\mathrm{HC}}(f_i, c_i) \\ &= \min\{d_i, f_i \times c_i\} \cdot r_i + R_i \cdot f_i \times c_i \\ &\quad + \min\{d_i, f_i \times c_i\} \cdot \nu_i. \end{aligned} \quad (16)$$

The above function mainly consists of two parts, F_i^{BC} and F_i^{SC}. F_i^{BC} is the transportation (or presented as navigation time in shipping) cost for carrier i; F_i^{SC} is the surcharges cost for carrier i, which includes F_i^{OC} (the surcharge fees excluding THC) and F_i^{HC} (the container handling cost for carrier i, resp.).

In this study, we stand at the shipper's point of view and make a more superior choice in the two modes of transport (mainly railway and shipping) through a comparative analysis of both the advantages and disadvantages of each mode. The deterrence game-theoretic strategy was used to measure the costs of each mode of transport, in which the changing scale of transport demand for shippers, service frequency of each mode, freight rate, and transport capacity are fully taken into consideration.

We define the incumbent carrier as carrier i, as well as the entrant carrier as carrier i^{-}. To be noted, here we take the transportation mode shipping as the incumbent carrier and railway as the entrant carrier. On this basis, we can develop a transportation mode choice model based on game theory, and it can be formulated as follows:

$$\min \quad \left(F_i^C, F_{i^-}^C\right) = \min \begin{pmatrix} \min\left\{d_i, f_i \times c_i\right\} \cdot r_i + R_i \cdot f_i \times c_i + \min\left\{d_i, f_i \times c_i\right\} \cdot \nu_i, \\ \min\left\{d_{i^-}, f_{i^-} \times c_{i^-}\right\} \cdot r_{i^-} + R_{i^-} \cdot f_{i^-} \times c_{i^-} + \min\left\{d_{i^-}, f_{i^-} \times c_{i^-}\right\} \cdot \nu_{i^-} \end{pmatrix} \tag{17}$$

$$\text{Subject to} \quad d_i + d_{i^-} = d, \tag{18}$$

$$f_i, f_{i^-} \in \{1, 2, \ldots, k\}, \tag{19}$$

$$c_i, c_{i^-} \in \Omega_c = \{c_1, c_2, \ldots, c_n\}, \tag{20}$$

$$r_i, r_{i^-} \in \Omega_r, \tag{21}$$

$$F_i^C, F_{i^-}^C \le \sigma, \tag{22}$$

where σ is the given threshold of the entry-deterrence objective, and the carriers' costs under its best response can be obtained by solving the optimization problem in (18)–(22).

In this model, the above equations show the constraints of the parameters, where σ is the given threshold of the deterrence objective, and the carriers' costs under its best response can be obtained by solving the optimization problem in (18)–(22). To be more specific, (18) shows the demand conservation constraint where the sum of the two modes' transport demands equals the total transport demand. Meanwhile, the side constraints for three decision variables are given by (19)–(22). Constraint (19) shows an integer weekly service frequency will be chosen and k is the maximum service frequency in a week. Constraint (20) means that there are n kinds of transport capacity setting plans (ship size or train length) for the shipper's decision-making. And (22) indicates the constraint of the range of freight rates. Generally, carriers change their freight rate into a sequence with equal intervals (e.g., $5/interval; other differences are also applicable). Where Ω_r is the discrete feasible set of variable r_i and based on the boundary constraint (21), we set $r_1 \ge r^{\min}$ as well as $r_m \le r^{\max}$.

As a shipper, we can use this deterrent game-theoretic model to compare the modes of shipping and railway, which compete mutually on different main variables such as freight rate, service frequency, shipping capacity, and other secondary parameters like reputation, transportation time, and so on, in order to choose the optimal mode of transport.

3.4. Algorithm. In this section, a numerical solution approach is developed to solve the deterrence game formulated by the model. In order to solve the practical problem, we use steps to make the solution more feasible. Firstly, set the parameter values for each carrier (according to the specific circumstances of the line from Hefei to Hamburg, in Step 1). Secondly, obtain the matrices for two carriers, and calculate the market share and the transportation cost of each mode (Steps 2 and 3). Then, we explain and analyze the results, in order to provide decision basis for the optimal selection of two transportation modes under certain conditions (Step 4). The details are shown in Figure 3.

4. Application and Results

The following application analysis was carried out to assess the effect of entry-deterrence strategy. In this study, an entry-deterrence game model was applied to develop the competition between two different modes of transportation, namely, shipping and railway, by setting a study case from Hefei in China to Hamburg in Germany. The model was developed in MATLAB R2013b, Intel I Core 2 Quad CPU Q9650 @ 3.00 GHz. The model development is as follows.

4.1. Preliminary Setting. In this application, we assume that the origin of the route is Hefei (China), where the route of "Hefei CR express" starts from Hefei, as showed in Figure 4.

In terms of starting time and the capacity, the shipping liners between China and Europe start a lot earlier and entail much larger capacity than the CR express trains, which makes the former more developed. Herein, in order to simplify the results, we assume that the shipping carrier is set as an incumbent carrier (denoted by carrier 1) and the railway carrier as an entrant (denoted by carrier 2). The various parameters are shown in Table 5.

At present, the basic freight rate for the CR expresses in B&R Initiative varies from 7,500 to 12,000 USD per FEU. However, some CR expresses (e.g., Chongqing-Duisburg, Zhengzhou-Hamburg) have government grants in order to lower the freight transportation cost by railway and to encourage shippers and manufacturing companies for long-term cooperation [8]. The basic freight rate of CR expresses is often lower than its original cost because of the financial subsidies from the government. To be more specific, the original basic freight rate is from 7,500 to 12,000 USD, and the subsidies from the government vary from 1,000 to 7,000 USD [8]. Therefore, the real basic freight rate for the CR expresses varies from 3,500 to 12,000 USD per FEU. As to shipping companies, the freight rate varies from 1,000 to 5,000 USD per FEU, which is normally much lower than the railway freight rate. However, when it comes to the problem we are investigating now, the purpose of this study is to establish those scenarios when it is meaningful to compare the two modes of transportation. In other words, when a firm wants to compare the two modes of transportation, the rates scale of the two modes must be comparable. So in this research, we

Table 5: Parameters used in application tests (source: author, adapted from references and Google Map).

Parameters		Value	Unit	Sources
Value of time, α		360	\$/day	Wang et al. [31]
Parameter in generalized cost function, β		−36	—	Wang et al. [31]
Dispersion parameter used to measure the degree of customers' perception errors on utility, θ		1.25	$\times 10^{-3}$	Wang et al. [31]
Elastic coefficient in demand function, η		1.25	$\times 10^{-4}$	Wang et al. [31]
Lower bound of basic freight rate of transporting per FEU for carrier i, $r_i^{\min}$		3,500	\$	Analysis of references and interview
Upper bound of basic freight rate of transporting per FEU for carrier i, $r_i^{\max}$		5,000	\$	Analysis of references and interview
Potential weekly container demand in the market, d_p		300	FEU	Assumed demand quantity by authors
Transporting time from Hefei to Hamburg for transportation mode i, T_i^S	Carrier 1	31	day	Interview of three logistics companies and Tables 1–3
	Carrier 2	15		
A score to reflect the reputation	Carrier 1 (λ_1)	5	—	Interview of three logistics companies
	Carrier 2 (λ_2)	8	—	Interview of three logistics companies
Terminal handling charges for company i, ν_i	Carrier 1	350	\$/FEU	Interview of logistics companies and Wang [8], Mo et al. [7], and Wang et al. [9]
	Carrier 2	2,000		
Transporting distance	Carrier 1	11,000	km	Google Map
	Carrier 2	12,277 (≈22,737)	nm (km)	Google Map

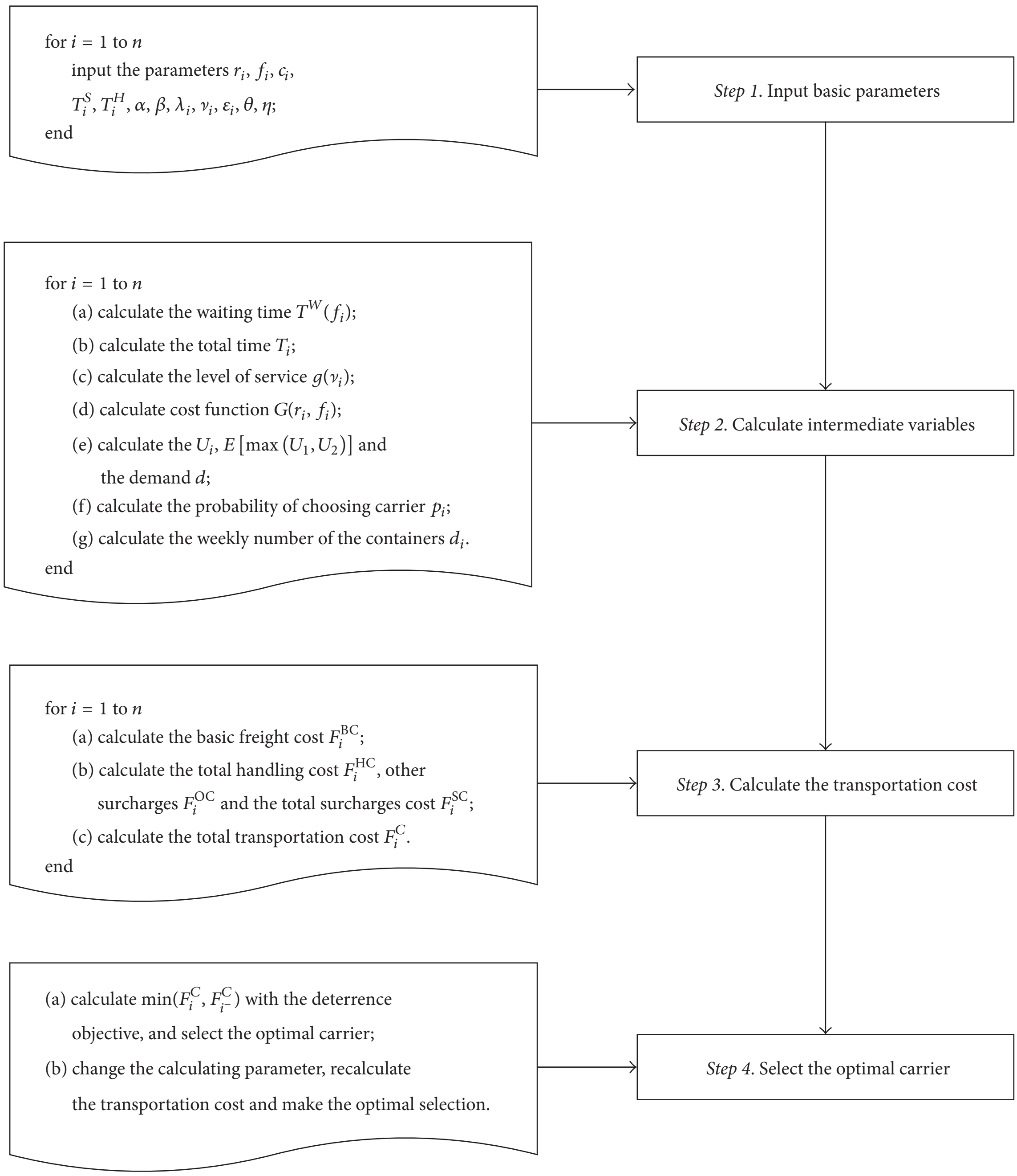

Figure 3: The algorithm of deterrence model.

define the upper and lower bounds of the basic freight rate at 5,000 and 3,500, respectively. In addition, the frequency of the CR express is at least 1 or 2 per week, while the shipping liner is at most once a week. With similar method, in order to balance the frequency and the capacity, we consider 2 CR block trains in one week as 1 train in this study. Accordingly, we set the potential weekly demand in the market as 300 FEU (which is in the middle of average capacity of railway as 50–60 FEU per train and shipping as 500–1,000 FEU per ship) to balance the difference of the two modes (these data come from the interviews of three logistics companies and references such as Wang [8], Mo et al. [7], and Wang et al. [9]). The navigation time (30 days) for carrier 1 (shipping) is calculated as an average navigation time by different shipping companies and adds a day's delivery time from Hefei to Shanghai Port, 31 days in total. For example, in Asia-Europe Express route in PIL, the navigation time from Shanghai Port to Hamburg Port is 37 days, while others (APL, COSCO, etc.) may have longer or shorter navigation time. Moreover, for carrier 2, there is one CR express, namely "Hefei CR express" which runs direct to Hamburg in 15 days. Additionally, since the Chinese government makes unremitting effort to ensure

Table 6: Simulated market share of deterrence model.

Deterrence objective (σ)	Service frequency (carrier 1)	Service frequency (carrier 2)	Total cost (10^5) (carrier 1)	Total cost (10^5) (carrier 2)
600,000	1	1	2.93834401	5.99423874
620,000	1	1	3.040454096	6.19922357
640,000	1	1	3.138887676	6.39846894
660,000	1	1	3.238445314	6.5973521
680,000	1	1	3.339851551	6.79881542
700,000	1	1	3.438504897	6.99845642
720,000	1	1	3.540809401	7.19962378
740,000	1	1	3.738800788	7.399702546
760,000	1	1	3.944699256	7.599855057
780,000	1	1	4.144096183	7.798951093
800,000	1	1	4.348494643	7.999625798
820,000	1	1	4.552293099	8.199999897
840,000	1	1	4.732502318	8.399864545
860,000	1	1	4.937300788	8.599989839
880,000	1	1	5.141499256	8.799893663
900,000	1	1.5	5.345097721	8.999859671
920,000	1	1	5.548096183	9.199996018
940,000	1	1.5	5.750494643	9.39992759
960,000	1	1	5.952293099	9.599747046
980,000	1	1	6.135800788	9.799874677
1000,000	1	1	6.338299256	9.999935619

Figure 4: Route from Hefei to Hamburg based on "Asia-Europe Express" in PIL (source: author, adapted from https://www.pilship.com/ and Google Map).

the smooth running of the Sino-Europe container trains (CR expresses), we propose that the reputation is higher than the liner ships operated by the shipping companies, at 8 and 5 (from the interview of three logistics companies), respectively. Additional data can be referred to in Wang [8], Wang et al. [31], Google Map, and other references.

4.2. Numerical Results. In this section, the effect of deterrence objective on these two transportation modes has been investigated to obtain their optimal responses. It is noted that carrier 1 (shipping) is assumed to be an incumbent in the market and carrier 2 (railway) is an entrant which poses a potential market threat to carrier 1. Consequently, it results in a deterrence game between these two carriers, the results of which suggest an optimal choice of carrier for consignors that focus on the cost of transportation. The deterrence objective is set to increase from 600,000$ to 1,000,000$ with each increment of 20,000$. Based on the deterrence competition model and solution algorithm, we give the deterrence effects that vary with increasing values in the deterrence objective (see Figures 5–8).

Firstly, Table 6 gives the service frequency and total cost for the two carriers with different deterrence objectives. We can see that both carriers mostly prefer to set their service

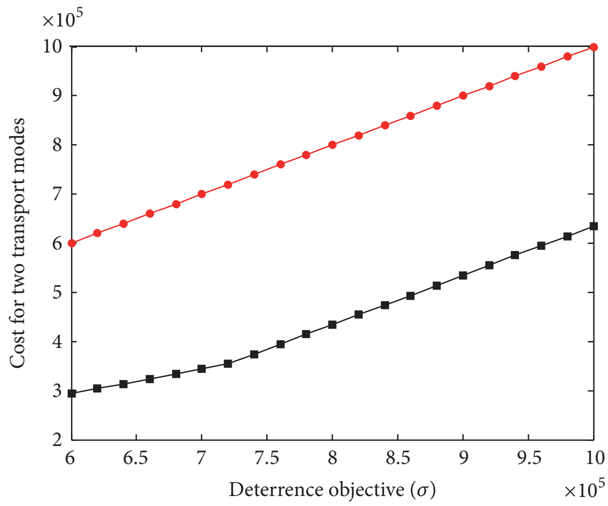

Figure 5: Total transport cost for the two carriers varying with the deterrence objective. Black square for carrier 1 (shipping); red circle for carrier 2 (railway).

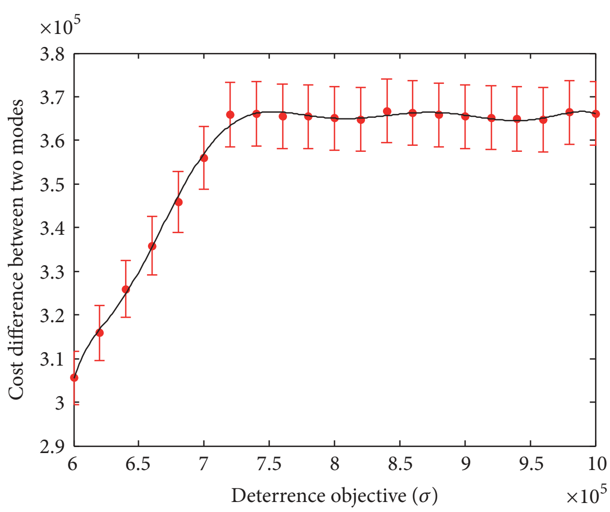

Figure 6: Cost difference between two carriers varying with the settled deterrence objective.

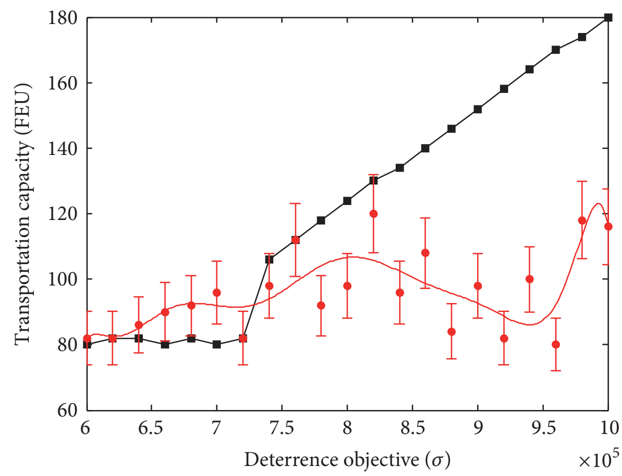

Figure 7: The transportation capacity for two carriers varying with the deterrence objective. Black square for carrier 1 (shipping); red circle for carrier 2 (railway).

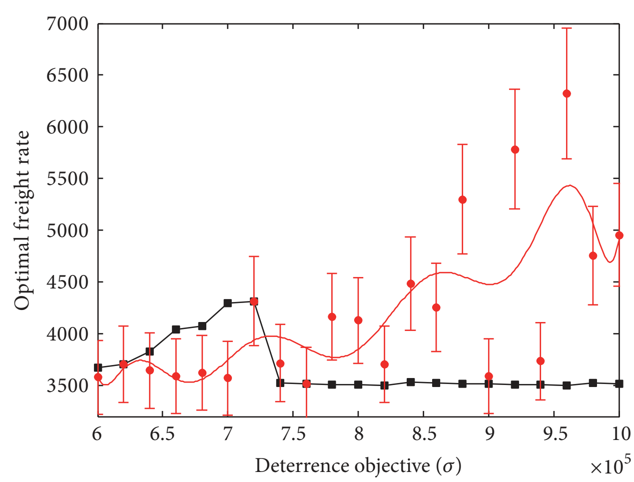

Figure 8: The basic freight rate for two carriers varying with the deterrence objective. Black square for carrier 1 (shipping); red circle for carrier 2 (railway).

frequency as one time except that frequency setting of carrier 2 is 1.5 in the case of deterrence being 900,000$ and 940,000$, whereby the required amount of service capacity can be worked out by changing the transportation capacity setting.

It can be seen from Figure 5 that the level of the transport cost for both carriers 1 (black square) and 2 (red circle) increases with the increase in deterrence which is obtained from Table 6. In fact, for the shipping carrier, the transport cost increases slowly at first and then increases faster with higher value in the deterrence objective. However, for the railway carrier, the cost always increases at a fast rate across the range of the given deterrence objective. What is more, it is clear that the transport cost of railway is always higher than that of shipping, which is as expected in the transportation market. In addition, we made an analysis of the cost difference between these two carriers (Figure 5). We note that the cost difference is increased as the deterrence objective increases from 600,000$ to 750,000$. When the deterrence objective is beyond 750,000$, the cost difference between two carriers tends to be a constant value of about 365,000$. It follows from Figure 6 that when the deterrence objective is set within a small range and thus the total cost is relatively low, it is better to choose the shipping transportation. This is because the shipping cost is much lower than railway and has a slow increment in the low deterrence objective region.

Figure 7 shows the transportation capacity for the two carriers (black square for carrier 1 (shipping) and red circle for carrier 2 (railway)) varying with values in the deterrence objective. It is found that railway's capacity experiences fluctuations with increasing deterrence values while shipping's capacity has a steady increment with higher value in the deterrence objective above 750,000$. Actually, when the deterrence is below 750,000$, carrier 1 always uses the shipping with capacity of about 80 FEU, while carrier 2 offers the railway service with capacity slightly above 80 FEU. As for the scenario of $\sigma > 750{,}000\$$, there is a big enhancement of capacity for carrier 1 changing from 80 FEU to 110 FEU; then its capacity linearly increases with increasing deterrence. The transport capacity of carrier 2, generally speaking, has a slow increment with much fluctuation and is always below that of carrier 1.

Variations of the basic freight rate for two carriers are plotted in Figure 8. Inspecting this figure, we note that the basic freight rate for carrier 2 (railway, red circle) is also in fluctuation and generally increases with increase of deterrence objective. Evidently, for carrier 1 (shipping, black square), it provides the basic freight rate that increases at first and then decreases to a stable value with higher deterrence from 750,000$ onwards. This stable basic freight rate is lower than that for carrier 2. When the deterrence is below 750,000$, the basic freight rate for shipping is a little higher compared to that for railway. It is shown in Figures 7 and 8 that when the cost is high (beyond 750,000$), the shipping carrier will increase its ship capacity and decrease its basic freight rate as the best response to the market demand. In practical application, the ship capacity is much larger than railway capacity. Therefore, the railway carrier has restrictions in transportation capacity, and its basic freight rate has to be enhanced.

5. Conclusion and Further Discussion

The present study discussed a competition between two transportation modes (shipping and railway) through developing a game-theoretic model. The deterrence strategy is utilized with consideration of economies of scale of the transportation capacity settings. Based on the deterrence model, each transportation mode's response to minimize its cost is evaluated by setting optimal service frequency, basic freight rate, and carrier capacity. The market share of each mode is determined by the logit-based discrete choice model. Furthermore, with the reverse deduction of formula, the study indicates the computing method to obtain the time value (α) of the cargo that the carriers transport. When making decisions about choosing the mode of transportation between continents, a shipper can use this method to estimate the different costs of the two modes and compare the difference of the time value of the cargos to reduce the expense during the whole transportation process. At the same time, a carrier can use this method to explore the direction to improve in order to be more competitive in the transport market.

In the competition, a carrier is an organization that transports products or service using their own facilities; and a shipper is a person or company that wants to send or transport goods. The competitions between the carriers are usually in the same transport mode. However, this does not happen all the time. Two transport modes can also be treated as two carriers in the same mode of transport (shipping or airline, etc.) in some situation. In this case, the railway and shipping also have a lot in common where they are exchangeable in many aspects. In addition, the entry-deterrence is about the incumbent and entrant of the same market, and the CR express is newly started mode with the advantage in transport time which can be transferred into the inventory cost of the cargos and the reliability in transport with safety insurance, while the disadvantage is its low capacity and high basic freight rate. It conforms to the features of an entrant. Additionally, the shipping carrier, with the advantage of low basic freight rate and high capacity, already runs in decades in the line between China and Europe. It is typically an incumbent in the market.

With the competitive relation between railway and shipping, there are two perspectives we can take. If we stand on the perspective of the shippers, the purpose of this study is to choose the optimal mode of transport or the optimal carrier through two carriers in different modes of transport. In the case study, in order to verify that this competition exists, we set some boundaries in scope of the basic freight rates, demand, market capacity, and time value. Moreover, we also make a simplification for the model so as to obtain more intuitive results. In a real market, there is often more than one carrier in one mode of transport (e.g., several carriers in a certain shipping line), but normally their basic freight rates are in the same range. Therefore, our bounds of the basic freight rates are set in a certain scope. However, there are not many choices for the shippers in one line. Our study endeavors to offer an option of methods to find the optimal carrier from one city to another. To sum up, our method is to choose the more competitive carrier or transport mode.

On the other hand, it is also reasonable if we stand on the perspective of the carriers. In general, the competition is believed to exist in carriers of the same transport mode in a certain line. However, this study presents a new type of competition, between the carriers in different transport modes. As for the shipping carriers, the demand market can be extended to some smaller-scale ones and make profits on its containerized character of the container transportation. And as for the demand market, the shipping carriers have advantage in freight rate (lower price) but disadvantage in reliability of transport time. Moreover, if a shipping carrier wants to explore a better market, it has to improve on the service and time reliability, to obtain more potential customers with high value cargos, whereas the railway operators, in order to place themselves in an advantageous position, have to increase a number of the expresses according to the marker demand on one hand and keep on shortening the transport time and transit time to expand its advantage in time reliability on the other hand.

Finally, the developed model is numerically evaluated by a case study of the intercontinental container freight transportation between Hefei (China) and Hamburg (Germany). The case study shows that deterrence effects largely depend on the deterrence objective, and the differential cost of two modes of transportation tends to be stable with higher values of the deterrence objectives. In the new intercontinental circumstance, the mode of railway transportation provides a new way to transport cargos between China and Europe.

In a way, the railway is relatively more expensive than the maritime transportation to some extent; however it has the advantage of lesser time. Railway is a new option for long distance transportation from China to Europe and shall continue to evolve in the new circumstance of the B&R Initiative. If the frequency is higher, the waiting time and cost will be significantly reduced. So, both the two modes of transportation have their own advantages, and container CR express has much potential in the future, especially for high value-added cargo.

As for further discussion, we set the time value of the transportation from Hefei to Hamburg as 360 USD per day in this study. However, this figure may vary from cargo to cargo (less or more than 360 USD) where, according to Wang [8], the high time-sensitive cargos may have the time value as 480 USD, whereas the low time-sensitive ones may have values at 120 USD per day. Moreover, we can reverse the equations in the model and treat the total cost model as a variable; in such case we can then obtain the relation and expression of time value (α) of the cargo and the total cost.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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