A Competitive Analysis of Chinese Coal Transport Routes in Intermodal Transport Network

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Abstract. The imbalance between coal production area and coal consumption area makes coal transport important to the development of coal industry. This paper analyzes different modes of coal transport including railway, railway-water and import, and constructs a generalized cost function of coal transportation. The competitiveness of different modes are studied through a case, and the result shows: the consumption price of coal under railway, railway-water and by import is respectively affected by the distance between consumption area and productive area, the distance between ports and consumption area, and the distance between import ports and consumption area; when railway freight rate increases, the market share of import increases, and the market share of railway and water-railway decreases; when water transportation freight rate increases, the market share railway and import increases, and the market share of water-railway decreases.

Introduction

In some countries, the distribution of coal production and coal consumption is imbalanced. Taking China for example, coal production distributes mainly in the west and north of China, but coal consumption distributes mainly in the east, which forms the pattern of “north coal transports to south, and west coal transports to east” in coal transportation. Due to the imbalance of coal production and consumption, the coal needs to be transported in space, which makes coal transport become the key link of coal logistics chain. As early as in 1981, Robert proposed that when the coal logistics cost becomes an important factor affecting the development of enterprises, intermodal transport should be applied to optimize the coal logistics system so as to reduce the coal logistics cost\textsuperscript{[1]}. 

Railway, water transport and highway are main transportation modes of coal. In practice, considering the limitations of railway and water transport on path layout, door to door transport can't be realized. Thus intermodal transport is often used in coal transport. When coal transport network is constructed, there will be more than one coal transport corridor for consignors to choose, such as highway transportation, railway transportation, or intermodal transportation, e.g. railway-water, highway-railway, or highway-railway-water transportation. The costs of different coal transport corridors differ a lot, which can affect consignors’ choices on the mode of transportation. Therefore, it is necessary to analyze the competitiveness of the coal transport routes under intermodal transport organization and the main factors influencing the competitiveness of intermodal transport, which can provide theoretical support for consignors’ choices on intermodal transport corridor and improving the efficiency of the transportation market.

Previous studies on competitiveness of coal transport corridors can be divided into the competitive
analysis of transporting by one single mode and the competitive analysis of intermodal transport. In the study of competitiveness analysis of transporting by one single mode, under the situation of limited growth potential of rail traditional bulk markets, Allan[2-3] focused on non-bulk rail freight activity in Britain, analyzed how to improve market share of the non-bulk rail freight, and further studied the railway transport policy impacting on competitiveness of railway transport. Fang[4] proposed a competitiveness model of freight corridor by the improved Logit method, a coal transportation corridor of western was taken as a case to study the competitiveness between the road and rail, and the change of the competitiveness was discussed while a new transport mode was introduced into the corridor. Liu[5] introduced the spatial pattern of inter-provincial coal input and output, analyzed the effect of railway coal transportation in different region, calculated the transportation cost of coal transportation. Wang[6] developed a mathematical model to quantify the market share of a given port, evaluated the impact of the landbridge system on the market shares of Asian ports, and illustrated the competitiveness of the Malacca and Singapore Straits by analyzing the changes in the market share of Singapore port.

On the basis of the previous study, some scholars studied the efficiency of intermodal transport. Arnold[7] dealt with the problem of optimally locating rail/road terminals for freight transport, analyzed the market shares of the combined traffic. Janic[8] developed a model for calculating comparable combined internal and external costs of intermodal and road freight transport networks, which took local and global air pollution, congestion, noise pollution, and traffic accidents into consideration. Ma[9] studied the reasonable scope of transportation by compared transporting the coals from Shendong, south Shanxi and north Shanxi to the South China and East China. Zhang[10] took the shippers of international container inland segment from Yiwu to Ningbo as research object, selected attributes of transportation chains, shippers and cargoes to construct transportation chain utility function, and analyzed the railway transportation chain share ratio incorporating time threshold. Tang[11] considered transport time and transport fares concerned by shippers, modeled the choice of transport schemes on rail-road intermodal network, which can be used to analyze the impacts of hubs delay on rail-road intermodal network quantificationally.

The researches on the competitiveness of transport corridor analysis usually consider the influence factors affecting the transport corridor choice to build general expenses function, which includes cost, time, reliability, security, service frequency, transport capacity[12,13]. However, when calculating the coal transport generalized cost, transportation cost and time cost are simplified and always calculate only in the middle process. The detailed characterization of each link cost of coal transportation process is not sufficient. In combination with the previous researches, this paper will analyze different transport modes of coal transport, and construct a generalized transport cost function of the coal logistics process. Combined with a case study, the competitiveness of the coal transport corridor and the impact on it by each link cost are analyzed, which can provide theoretical support for constructing reasonable dispatching plans.

Mathematical Model of Market Share Estimation

General Process of Coal shipment in China

Coal shipment involves multiple links. The coal is transported by highway or railway from the coal mine to the consumption areas or the ports for launching. While the coal is transported to the ports, it will be transported by water to the ports for landing, and then be transported by highway or railway to the coal consumption areas. The general process of coal shipment involves multiple transportation enterprise, such as coal production enterprises, coal sales enterprises, coal consumption enterprises, railway enterprises, and port enterprises. The mutual cooperation of the enterprises makes up the whole process of coal shipment. Based on the general process of coal shipment, the whole cost of coal contains the coal price at mine, related expenses of taxation, transport costs, handling charges and so on. The general process of coal shipment and costs is as shown in Figure 1.
Figure 1. The general process and costs of coal shipment.

Notation, Assumptions and Problem Statement

To represent the coal transport corridor or routes in intermodal freight transport network, we use an $x$-$y$ coordinate system as shown in Figure 2, in which port $P$ is on the $x$-axis. The network may also include several other available ports such as $P_1$ and $P_2$. The network is represented by directed graph $G=(N, L)$, where $N$ and $L$ represent the sets of nodes and links, respectively. Let $H \subseteq N$, $O \subseteq N$, $D \subseteq N$ be the sets of the rail transfer terminals, origins and destinations in network $G$, respectively. In Figure 2, it can be seen that ports $P$, $P_1$ and $P_2$ are transfer terminals, i.e., $P, P_1, P_2 \in H$.

Let $o=(x, y) \in O$ denote an origin node with coordinates $(x, y)$. The coal wholesalers located around $o$ desire to hire an intermodal operator or intermodal transport supplier to transport coal from $o$ to a given destination $d \in D$. All the intermodal routes available to intermodal operators are denoted by set $R_{od}$. Let $r$ be an intermodal route included in $R_{od}$, i.e., $r \in R_{od}$. The route $r$ commonly consists of several transfer terminals and links. Indicator $\delta_{r od}$ equals one if the route $r$ pass through link $l \in L$, otherwise equals zero. The value of indicator $\delta_{r h od}$ is taken as one if a transfer terminal $h \in H$ is on route $r$ and the coal transported along $r$ is transshipped at the terminal, otherwise zero.

The following assumptions are made: (i) Transport cost and time incurred on a link $l \in L$, denoted by $C_l$ and $T_l$, respectively, are reasonably assumed to be randomly distributed, since the variables vary based on intermodal carriers, operational conditions and market prices for transport services. (ii) Transshipment cost incurred at transfer terminal $h \in H$, $C_{th}$, is also assumed as a random variable. (iii) At a transfer terminal coal arrive in batches in accordance to a compound Possion process. (iv) The time for handling a particular coal shipments at a transfer terminal is...
generally distributed random variable. (v) Transport times and costs incurred on links and at transfer terminals are assumed to be independent, as the operational processes on them can be considered to be mutually independent. (vi) Intermodal operators are assumed to choose the route with maximum utility from $R_{od}$ to transport coal from the location $o$ with coordinates $(x, y)$ to destination $d$.

Accordingly, it obtains based on assumptions (i) and (ii) that

$$C_l = c_l + \xi_l, \quad T_l = t_l + \omega_l, \quad l \in L$$ (1)

$$C_h = c_h + \xi_h, \quad h \in H$$ (2)

where $c_l$, $t_l$, $c_h$ are expected values of $C_l$, $T_l$ and $C_h$, respectively. $\xi_l$, $\omega_l$ and $\xi_h$ are three random error terms with zero means which reflect the variations in transport cost, time of the link $l \in L$ and transfer time of $h \in H$, respectively. Furthermore, assumptions (iii) and (iv) give rise to a random transfer time at $h \in H$, denoted by $T_h$.

$$T_h = t_h + \omega_h, \quad h \in H$$ (3)

where $t_h$ is expected value of $T_h$ and $\omega_h$ represents the random error term with zero mean.

According to assumption (v), transport cost and time of route $r \in R_{od}$ can be written as,

$$C_r = \sum_{l \in L} C_l \cdot \delta_{od}^l + \sum_{h \in H} C_h \cdot \delta_{od}^h$$ (4)

$$T_r = \sum_{l \in L} T_l \cdot \delta_{od}^l + \sum_{h \in H} T_h \cdot \delta_{od}^h$$ (5)

Accordingly, the random utility of route $r$, $U'_{od}$, can be defined as follow,

$$U'_{od} = -C_r - \beta(x, y) \cdot T_r$$ (6)

where $\beta(x, y)$ is the Value of Time (VOT) perceived by the coal wholesalers located at $o$ with coordinates $(x, y)$ and able to convert time to a monetary value. VOT can reflect value of time perceived by intermodal operators or intermodal operators and it quantitatively gauges the weight of transport time in determining an intermodal operators’ preference toward intermodal routes.

**Market share Estimation**

The market share of coal transport routes in intermodal transport network is able to reflect the aggregate results of coal end-users’ choice behaviors, which directly embodies coal transport routes’ competitiveness. If all coal consumers choose a route with maximum utility, the value of market share of coal transport route in intermodal freight transport network will equal the probability that consumers choose these routes. Therefore, a discrete choice model based on random utilities is developed in this subsection to represent the choice process of consumers.

The market share of coal transport routes in the studied intermodal transport network can be approximated by the probability of the route being selected by coal consumers from available coal intermodal transport routes. Then, it can be written as,

$$M_i = \Pr[U'_{od} \geq U'_{od} \mid i \neq j, i \in R_{od}, \forall j \in R_{od}]$$ (7)

As coal consumers will choose an intermodal transport route to maximize their utility, the standard multi-normal Logit model can be able to be used to form a closed form market share model. Based on the above references, we refer to a coal transport route’s market share in the intermodal freight transport network as below,
\[ M_i = \frac{\sum_{j \in \mathcal{R}_d} e^{U_{ij}}}{\sum_{j \in \mathcal{R}_d} e^{C_{ij} - \beta(x,y)T_i}} \]  

(8)

Case Studies

Background of the coal shipment in the Huazhong Area

To illustrate our approach, an emerging coal consumption area in the Central China, the Huazhong Area is selected as typical case study in this section. This area is a geographical region that covers the central area of China and includes the provinces of Henan, Hubei and Hunan, as Jiangxi is sometime also regarded to be part of this region. In the context of the Rise of Central China Plan by the China’s State Council in 2004, Huazhong Area is becoming the largest consumer of coal due to power production, industry and manufacturing use driven by economic development. Generally, Three-west Area including the Inner Mongolia, Shanxi and Shaanxi provinces is the main coal producing areas in China. Note that as the districts of Eerduosi, Shuozhou and Yulin are the most important coal producing counties on Three-west Area, we assume that all coal shipment from this region are transported to the Huazhong Area through these three countries. For simplicity, we only consider main consumption counties on the Huazhong Area and important transfer seaports on China’s coast, as shown in Figure 3.

Coal shipment from the Three-west Area to end-users on the Huazhong Area can be able to be transported directly by railway freight lines that mainly refer to vertical mainlines such as Beijing-Kowloon Railway, Beijing-Guangzhou Railway. In addition, coal shipment from coal mines to end-users can also be able to be transported to seaports nearby Bohai Gulf by horizontal railway mainlines such as Daqin Railway and Shuohuang Railway, and then shipped to seaports on east coast of China, and finally transported to the destination via railway connecting the Huazhong Area. The detailed process and responding cost for the two main routes can be found in Figure 1. Moreover, it is noted that exported coal from overseas can be unloaded at seaports on south coast of China, and the transported to the end-users on the Huazhong Area. With the competition of the three routes of coal shipment, it is necessary to evaluate their Competitiveness.

![Figure 3. Hinterlands and intermodal freight transport network for the case study.](image-url)

Parameters Calibration

Time and Costs for railway and waterway transportation

The calculation methods for transportation cost and time for Chinese railway are listed in Table 1 according to the statistical data from the Custom Service Centre of Chinese Railways and The Shanghai Shipping Exchange.

179
Table 1. Parameters for transportation cost and time of railway and waterway.

<table>
<thead>
<tr>
<th>Mode</th>
<th>Cost Function $C_l$ (RMB/kilometer-ton)</th>
<th>Time Function $T_l$ (h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Railway</td>
<td>value*</td>
<td>$L/80km/h$</td>
</tr>
<tr>
<td>Waterway</td>
<td>value**</td>
<td>$L/30km/h$</td>
</tr>
</tbody>
</table>

Note: Railway and waterway cost is obtained from Sinorail Customer Service Center and the Shanghai Shipping Exchange, respectively. $L$ is the distance between the origin and destination.

**Time of handling as well as costs for transshipment**

The operational department in coal production/consumption counties and seaports charges different kinds of fees for services, and the total charges for each node are shown in Table 2. The handling efficiency of nodes can be reflected by a constant that identical for each node. Moreover, the cost between railway stations and seaports is 25 thousand RMB per 10 thousand ton.

Table 2. Parameters for handing in the nodes of study area.

<table>
<thead>
<tr>
<th>Node</th>
<th>Handling Efficiency (ton/h)</th>
<th>Handing Time $T_h$ (h/10^4 ton)</th>
<th>Charges $C_h$ (10^4 RMB/10^4 ton)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal production area</td>
<td>250</td>
<td>40</td>
<td>5.6</td>
</tr>
<tr>
<td>Coal consumption area</td>
<td>250</td>
<td>40</td>
<td>5.6</td>
</tr>
<tr>
<td>Seaports</td>
<td>250</td>
<td>40</td>
<td>11.2</td>
</tr>
</tbody>
</table>

**Results**

**Scenario Analysis**

The consumption price of coal with different distances between consumption area and productive area under railway transportation, under railway-water combined transportation, and by import are shown as Figure 4(a)-(b), respectively.

![Figure 4](image)

**Figure 4.** Consumption price of coal under different transportation mode.

Figure 4(a) shows that when the distance between consumption area and productive area increases, the consumption price of coal under railway transportation increases. As when the distance increases, the cost of transportation increases. The consumption price of coal under railway transportation has a wider range when there’re more available routes between consumption area and productive area, such as Yingtan has a wider range because more routes can be chosen, and Jingmen has a narrower range because less routes can be chosen. Accordingly, the consumption price of coal under railway transportation is positive correlated with the distance between consumption area and productive area, and it has a wider range when more available routes can be chosen.

Figure 4(b) shows that when the distance between consumption area and productive area increases, the consumption price of coal under railway-water combined transportation firstly decreases and then increases. However, the rule matches with the distance between ports and consumption area. When the distance between ports and consumption area decreases, transportation cost decreases and the consumption price of coal decreases, and vice versa. The consumption price of coal under combined transportation is therefore positive correlated with the distance between
ports and consumption area, and the coal consumption price of different cities under railway-water combined transportation nearly range in the same degree.

Figure 4(c) shows that when the distance between consumption area and productive area increases, the consumption price of coal by import decreases. However, the rule matches with the distance between import ports and consumption area. When the distance between import ports and consumption area decreases, transportation cost decreases and the consumption price of coal decreases, and vice versa. The consumption price of coal by import is positive correlated with the distance between import ports and consumption area, and when the consumption price of coal under railway transportation is higher, the consumption price of coal by import is lower.

**Sensitivity Analysis**

The market shares of routes under railway transportation, railway-water combined transportation and import with different railway freight rate and waterway freight rate are shown as Figure 4(a)-(b), respectively.

![Figure 5](image)

**Figure 5. Market shares of routes with different freight rate for railway and waterway.**

Figure 5(a) shows that when railway freight rate increases from -50% to +50%, the competence of import becomes stronger and the market share of import increases from 24.8% to 30.6%. At the same time, the competence of railway and water-railway becomes weaker and the market shares of them decreases from 75.2% to 69.4%. The trend corresponds with the fact that when railway freight rate increases, the cost by railway increases, and the market shares including railway and railway-water decrease. Also, the market shares of railway transportation and railway-water combined transportation decreases by 2.4% and 3.4% respectively. In conclusion, when railway freight rate increases, the competence of import becomes stronger and the competence of railway and water-railway becomes weaker.

Figure 5(b) shows that when water transportation freight rate increases from -50% to +50%, the competence of railway and import becomes strong. The market share of railway increases from 39.5% to 42.0%, and the market share of import increases from 26.9% to 28.3%. The market shares of railway and import increases by 2.3% and 1.4% respectively. At the same time, the competence of water-railway becomes weaker and the market share decreases by 3.8%. The trend corresponds with the fact that when water freight rate increases, the cost by water increases, and the market share of railway-water decreases. In conclusion, when water freight rate increases, the competence of railway and import become stronger and the competence of water-railway becomes weaker.

**Conclusion**

(1) The consumption prices of coal under different modes are affected by different parameters. The consumption price of coal under railway transportation is positive correlated with the distance between consumption area and productive area, and it has a wider range when more available routes can be chosen. The consumption price of coal under combined transportation is positive correlated with the distance between ports and consumption area, and the consumption price of coal of different cities under railway-water combined transportation nearly range in the same degree. The consumption price of coal by import is positive correlated with the distance between import ports and consumption area, and when the consumption price of coal under railway transportation is higher, the consumption price of coal by import is lower.
The market shares of different modes are affected by railway freight rate and water freight rate. When railway freight rate increases, the competence of import becomes stronger and the competence of railway and water-railway becomes weaker. When railway freight rate increases from -50% to +50%, the market share of import increases by 5.8%, and the market shares of railway and water-railway decreases by 2.4% and 3.4% respectively. When water transportation freight rate increases, the competence of railway and import become stronger and the competence of water-railway become weaker. When water transportation freight rate increases from -50% to +50%, the market shares of railway and import increases by 2.3% and 1.4% respectively, and the market share of water-railway decreases by 3.8%.

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References


