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Coal logistics system: efficiency evaluation model under the big data circumstance

Coal is the main energy in the supplying structure of energy system in China. It has its own straits such as large in volumes, difference in distribution on the earth. Its transport efficiency evaluation become very important in the energy supply chains. In this paper, transport efficiency analysis model of coal Logistics network is introduced, where evaluation model is a new method. It can be used in coal logistics evaluation in many other area outside of China.

Keywords: Transportation Routine, Transport Efficiency Analysis, Coal

I. Introduction

Coal is a kind of important basic energy and also non-renewable resource. With the changes in energy production and consumption situation, coal occupies an increasingly important position in basic energy structure. How to make better use of coal resources, so that the coal resources realize smooth flow and rational allocation means great significance for easing energy shortage and promoting the development of the national economy. To make this, the important role of coal logistics can not be neglected. In addition to the logistics system characteristics of general industrial enterprises, coal logistics system also has the inherent characteristics decided by coal production: (1) Multiple logistics nodes, mainly multiple hold points during coal movement. Completion of coal production process needs multiple links, and a series of processes is needed for coal to go from the origin to the end consumer groups. (2) Long logistics line. Coal movement needs a long-distance transport with a variety of transport modes and transport means. Origin of coal is generally away from town, arterial road and point of consumption, so the shipment distance is long from the origin to point of consumption and usually collaboration of a variety of transport modes is needed. (3) Multiple logistics links. Coal logistics consists of multiple links including coal washing and processing, storage, transport and supply of raw materials, comprehensive utilization of waste ore, etc. The above characteristics suggest that coal logistics is not a simple linear process, but a multi-link, non-linear network system in terms of its structure. For the study of coal logistics, we should combine the actual situation of coal enterprises, and, based on in-depth analysis of network structure, characteristics and various links of coal logistics, carry out research from network characteristics of coal logistics to build a theoretical system of coal logistics network study.

Main modes of coal transport include railway, waterway and highway, which may be single-mode direct transport or multimodal transport of railway, highway, waterway. Wherein, railway traffic volume accounts for about 60% of the total coal traffic volume, waterway traffic volume accounts for about 30% of the total, highway traffic volume accounts for about 10% of the total. At present, railway transport is the main coal transport mode in China [1-3]. Thanks to its good technical performance such as rapid speed, large volume, low cost, high security, low energy consumption, strong continuity, good universality, railway transport has always been China's leading transport mode for coal logistics. Currently, for China's coal transport, railway is depended for inland transport, while sea transportation is used for supplementary. With the rapid industrial development in coastal areas and rapid increase in demand for energy, to take full advantage of intermodal transport of "railway-sea" can not only ease tensions in China's rail coal transport, but also meet the demand for energy of economically developed coastal areas. In recent years, with the rapid development of economy and the substantial increase in demand for coal, rail coal transport capacity is inadequate [4, 5]. Highway coal transport, with its extensive highway network, flexible transport, enjoys rapid development, becoming an important supplement to rail coal transport. However, highway transport, due to its small traffic volume and high cost, is generally applicable to internal transport of coal bases, or short regional transport of railways, ports for coal collection and distribution.

2. Transportation routine

In the coal logistics transport network system, the infrastructure in the network can be abstracted as node, the transport route can be abstracted as edge, so that the coal logistics transport network is converted to a network topology constituted by node and edge. The coal logistics transport network topology can be represented by graph

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theory. The various logistics nodes $V_1, V_2, \ldots, V_n$ can be abstracted as a set of points V, and the transport route can be abstracted as the edge set E. $E \subseteq V \times V$ is the set connecting edges of the two elements in V. Coal logistics transport network can be represented by the diagram . Coal logistics transport network is a directed graph, where each path is a series system composed by sections. In the linked network, all valid reachable paths linking between random OD pair constitute a parallel system [6-8]. Moreover, there is a corresponding weight to each edge, such as transport distance, traffic volume, etc., so the coal logistics transport network is a weighted network. Transport route analysis of coal logistics transport network includes coordination and cooperation between each node in the system[9], as well as integration, connectivity of route connecting the nodes, which proceeds with study specifically from point to point, route to route, point to route, chain to chain, etc.

3 Transport efficiency analysis model of coal logistics transport network

Due to exclusivity and dependence of transport mode for transport infrastructure, this paper, from the two aspects of transport mode E_c and transport route E_l, analyzes transport efficiency E_r of coal logistics transport network, as shown in Formula 1:

$$E_r = F(E_c, E_l) \quad \ldots 1$$

Transport efficiency analysis model structure of coal logistics transport network is shown in Fig.1. Wherein, transport carrying capacity of different coal logistics transport modes is analyzed from traffic volume, time, distance, which also provides a theoretical foundation and basis for transport efficiency study such as availability, accessibility, fitness of transport network.

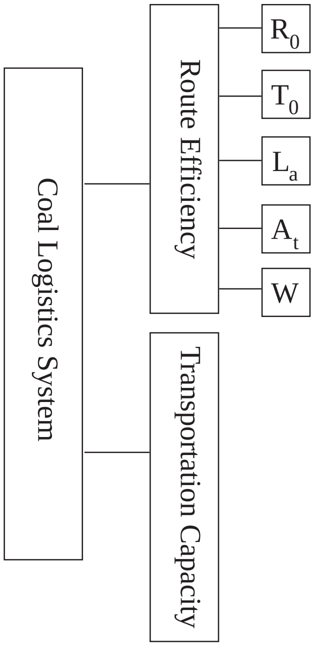

Fig.1 Transport efficiency analysis model of coal logistics transport network

This paper analyzes efficiency of transport modes from carrying capacity. The measurement indexes [10] include: transport turnover R_0, turnover time T_0, average transport distance L_a, average transit time A_t, average transit time per mile W, etc., as shown in Formula 2:

$$E_c = F(T_0, L_a, A_t, W) \quad \ldots 2$$

Three important measurement indexes are adopted in this paper for efficiency analysis of transport routes, namely transport network availability R, reachability D, moderation E, as shown in formula (3):

$$E_l = F(R, D, E) \quad \ldots 3$$

3.1 TRANSPORT CARRYING CAPACITY ANALYSIS OF LOGISTICS NETWORK

Transport carrying capacity of logistics transport network refers to, on the condition of meeting requirements of traffic user, resource constraints and traffic service level, the maximum traffic carrying capacity of the transport network. The measurement indexes adopted in this paper are as follows:

(1) Traffic turnover R_0

Traffic turnover is the product of volume and transport distance, to be calculated as Formula (4). It is used to measure the spatial displacement intensity in transport carrying capacity analysis index.

Traffic turnover R_0 = volume* transport distance
(unit: ton* kilometer) ... 4

(2) Time turnover

Time turnover is the product of volume and transit time, to be calculated as Formula (5). It is used to measure time displacement intensity in transport carrying capacity analysis index.

$G = (V, E)$

Time turnover T_0 = volume* transit time
(unit: ton * day) ... 5

(3) Average transport distance

Average transport distance is traffic volume divided by traffic turnover. Equal to average displacement distance of transport object on the transport network, it reflects spatial cohesion of logistics transport network, to be calculated as shown in Formula (6):

$$L_a = R_0 / V \quad \ldots 6$$

(4) Average transit time

Average transit time is traffic volume divided by time turnover. In transport carrying capacity analysis index, it reflects average time span of transport object in the network. Under certain demand, the longer average transit time is, the lower logistics transport network service efficiency is. It is calculated as shown in Formula (7):

$$A_t = T_0 / V \quad \ldots 7$$

(5) Average transit time per mile W

Average transit time per mile is either traffic turnover divided by time turnover, or average transport distance divided by average transit time. As an important index for service efficiency of logistics transport network, it reflects comprehensive technical and management level of logistics transport network, to be calculated as shown in Figs.3-8.

$$W = \frac{T_0}{R_0} = \frac{A_t}{L_a}$$

3.2 Availability Analysis of Logistics Transport Network

Availability of logistics transport networks includes section availability, path availability, OD pair availability and network availability, respectively referring to probability of normal use of section, path, OD pair and network [11].

(1) Section availability

Availability γ_α of section α is calculated as shown in Formula (9). The greater γ_α is, the higher availability and stability of section α are.

$$\gamma_\alpha = \frac{\mu_\alpha - \chi_\alpha}{\mu_\alpha} \forall \alpha, \chi_\alpha \le \mu_\alpha \qquad \text{... (9)}$$

In the formula μ_α – maximum volume of section α; χ_α – volume of section α; when $\gamma_\alpha \ge \mu_\alpha$ –make $\gamma_\alpha = 0$

(2) Path availability

Path is a result of series connection of component section. Availability $R_{i-j,\ k}$ of *k*-th path between the nodes *i*, *j* is calculated as shown in Formula (10)[12]:

$$R_{i\text{-}j,k} = \prod_\alpha \gamma_\alpha \delta^{i,\ ,}_{\alpha,\kappa}, \forall i,j,k \qquad \text{... 10}$$

In the formula γ_α – availability of section α; $\delta^{i,\ ,}_{\alpha,\ ,}$ – if section α is on the *k*-th path between connection OD pairs *i*, *j*, its value is 1, otherwise 0

(3) OD pair availability

By parallel connection of all available paths between OD pair, availability R_{i-j} of OD pairs *i*, *j* can be obtained. The calculation formula is shown in (11):

$$\mathrm{R}_{\mathrm{i\text{-}j}} = 1 - \prod_{\mathrm{i}} (1 - R_{i-j,k}) \qquad \text{... 11}$$

In the formula R_{i-j} – Availability of *k*-th path between OD pairs *i*, *j*

(4) Network availability

Network availability R_G is expressed as the arithmetic mean of availability of all node pairs in the network and calculated as shown in Formula (12):

$$R_G = \frac{\sum R_{i,\ j}}{n} \qquad \text{... 12}$$

3.3 Reachability Analysis of Logistics Transport Network

Reachability, also known as accessibility, refers to the degree of convenience for integrated transport network nodes to reach each other and the degree of smoothness of transport network traffic circulation [61]. Average impedance is adopted in this paper to indicate reachability of node and the overall network. Average impedance was put forward by Allen, which has become one of the most widely used models in study of network reachability.

(1) Node reachability

Reachability of node I is expressed as the arithmetic mean D_i of the shortest path distance between a node and other nodes in the network, and calculated as shown in Formula 13:

$$\mathrm{D_i} = \sum_{\substack{\mathrm{j=1} \\ i \ne j}}^{N} d_{ij} \Big/ M, (j = 1,2,...N) \qquad \text{... (13)}$$

In the formula N – number of nodes in the network;

M – number of reachable nodes in the network;

$\mathrm{d}_{\mathrm{i-j}}$ – the shortest path distance between nodes *i*, *j* in the network

(2) Network reachability

Network reachability is the arithmetic mean of reachability of all nodes, to be calculated as shown in Formula 14:

$$D = \sum_{i=1}^{N} D_i \Big/ O \qquad (14)$$

In the formula

D_i – node reachability from node *i*.

O – number of starting points in the network.

3.3 Fitness Analysis of Logistics Transport Network

Moderation of logistics transport network is also known as saturability. Its measurement indexes include efficiency of path between OD pairs, fitness of network carrying capacity and neutralized supply equilibrium coefficient.

(1) Efficiency of path between OD pairs, E

Efficiency of path between OD pairs, E, is used to reflect the gap between traffic situation and the best situation of OD pairs. The closer to 1E is, the closer to the best situation the transport situation between OD pairs is, and the higher path service efficiency is. It is expressed as the ratio of travel distance or time of the shortest route and the actual travel distance or time and calculated as shown in formula 15:

$$E = d \sum_{k=1}^{n} V_k \Big/ \sum_{k=1}^{n} d_k V_k \qquad \text{... (15)}$$

In the formula E – efficiency of path between OD pairs; V_k – actual volume of path *k* between OD pairs; d_k – travel distance or time of path k between OD pairs;

d – travel distance or time between OD pairs;

(2) Transport capacity fitness of network, V/C

Transport capacity fitness of network, V/C, is expressed as the ratio of total actual traffic volume of all routes in the network and total designed throughput. It reflects the degree of network congestion and the degree of adaptability to logistics transport supply and demand, to be calculated as shown in formula 16:

$$V/C = \sum_{i=1}^{n} V_i l_i \Big/ \sum_{i=1}^{n} C_i l_i \qquad \text{... (16)}$$

In the formula l_i – the length of the i-th network channel;

n – the total number of network channels;

V_i – the actual traffic volume of the i-th network channel;

C_i – the designed throughput of i-th network channel;

V/C – Network transport capacity fitness

According to Scientific Research Institute of the Ministry of Communications, assessment results of transport network status are divided into: advance adaptation, basic adaptation, inadaptation, quite inadaptation [61]. The evaluation criterion is as follows:

$\mathrm{V}/\mathrm{C} \le 0.7$, network transport capacity advancing demand;

$0.7 < V/C \le 0.85$, network transport capacity geared to demand;

$0.85 < V/C \le 1$ Network transport capacity is basically adapted to demand; $1 < V/C \le 1.5$, network transport capacity is not adapted to demand; 1.5?V/C, network transport capacity is quite not adapted to demand.

(3) Integrated supply equilibrium coefficient h

Integrated supply equilibrium coefficient h[61] is calculated as shown in 3-17. It reflects distribution of total traffic volume in various modes of transport and utilization rate of all transport resources. The closer to 0 h is, the more reasonable traffic volume distribution among the various means of transport is, and the higher utilization rate of transport resources is.

$$h = \sqrt{\frac{1}{n} \times \sum_{i=1}^{n} (V_i/C_i - V/C)^2} \qquad \text{... (17)}$$

In the formula n – the total number of the network channels;

V_i – the actual traffic volume of the i-th network channel;

C_i – the designed throughput of i-th network channel;

V/C – network transport capacity fitness

4. Conclusion

Taking into account exclusivity and dependence of transport mode for transport infrastructure, this paper analyzes and studies transport efficiency of coal logistics transport network from the two aspects of transport mode and transport route. First, it introduces status and role of the three transport modes in coal transport, namely railway, waterway and highway. Then, five indexes are used to measure traffic carrying capacity. For transport routes, three important measurement indexes, namely availability, reachability, moderation, are used for efficiency analysis. Wherein, availability analysis analyzes probability of normal use from four aspects of section, path, OD pair and network. Average impedance is used to indicate reachability of nodes and overall network. Moderation measurement indexes include efficiency of path between OD pairs, network carrying capacity fitness and neutralized supply equilibrium coefficient.

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