

Strategies for Optimizing Public Train Transport Networks in China: Under a Viewpoint of Complex Networks

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Abstract: Under a viewpoint of complex networks, a new method for optimizing public train transport networks (PTTNs) in China, named ‘Betweenness + Efficiency’ combinatorial method, is proposed in this paper. Take the Chinese Train Transport Net as an illustration. Firstly, we constructed related networks and analyzed some basic statistical properties. It was founded that these networks are positive-degree-correlation complex networks, which is between regular networks and small-world networks. Secondly, a new method, which connects betweenness centralization and global efficiency, was suggested to choose new lines of train transport designing. Numerical experiments verified: all the suggested lines added by our method can improve the global efficiency of existed PTTNs. Add a single line leading the global efficiencies up to 4.69%, and if integrated the six lines will leading the global efficiency up to 15%. This research can be referred by experts majored in such typical fields.

Keywords: complex networks; betweenness + efficiency combinatorial analysis method; betweenness; efficiency

1 Introduction

As an interdisciplinary subject, complex networks have received tremendous recent interest from the scientific community because of their flexibility and generality in the description of the natural and manmade systems. Recently, both the small-world networks^[1] and the scale-free network^[2] appear in statistical physics, which set off a wave of research about complex networks^[3-6].

Rail transport plays a very important role in national life and economic development, many researchers have built a variety of railway networks to study the nature of this particular transport system, by a large number of empirical studies, the researchers found that railway express network has a typical complex system structure and feature, this discovery laid a solid foundation in the study of the characteristics and the topology properties of the railway express system^[3-6]. Recently, W. Zhao, who had pointed out the methods of construction real network, usually set the site as a “node” and the track as an “edge”. Their statistical studies have shown that, the average clustering coefficient of the railway networks is approximately zero and have a typical tree-network structure^[7].

Similarly, this paper intends to study the Chinese Railway Express network using complex network theory. First of all, set the “operating sites” as a “node”, the “line” of linking the two sites as an “edge”, constructed the Chinese Railway Express network, in order to optimize the Express network structure, we constructed the national railway transportation network in the same way

according to the existing railway networks and long-term planning. This paper will analyzed some basic characters of these two networks. In addition, to improve the efficiency of the CTTNs, this paper proposes a new ‘betweenness + efficiency’ combinatorial analysis method.

2 Network Construction and Its Characteristics

2.1 Network Construction

Reference to the national railway line and the CTTNs diagram (**Figure 1**) (where the orange line in the picture represent the Chinese Train Transport Network)^[12], by considering the existing operational site as “node”, the railway line as “edge”, a network to reflect the actual link of the railway line is achieved.

In the following analysis, we call them the whole railway networks and CTTNs, separately. The former one contains 385 nodes, 1379 edges, and there are three connected sub-sets. We will discard the railways in Hainan and Taiwan Province, so we can ensure that the remaining part of the railway network is a connected graph; the latter contains 170 nodes, 532 edges (discarded the isolated nodes Zhuhai and Putian) and this treatment has no effect for optimizing the network.

In addition, **Figure 2** shows the 2008 version of the national railway planning diagram^[12]. We can calculate the relevant figures of the two networks, **Figure 3** and **Figure 4** show the topology diagram of the **Figure 1** which contains two networks.



Figure 1. The national railway line and the CTTNs diagram of China



Figure 2. The national railway planning diagram of China

2.2 Basic Characters of the Networks

Figure 4 shows the degree distribution diagram of the railway networks and the CTTNs. It can be seen; there are only four cases of node degree values, and the node degree value of 2 accounts for the vast majority. This shows that the structure of the CTTNs is very simple, generally close to hand in hand or chain network. In contrast, the degree distribution of the national railway network is more complex, but there exist a certain difference with random networks of the same scale. It is a realistic type of network that between the random networks and rule networks.

Table 1 shows some basic characters of the CTTNs (**Figure 3** up) and the railway network (**Figure 3** down). It reveals two types of interconnected transport network's typical characteristics and contacts (in fact, except two isolated base, the CTTNs can be regarded as a connected sub-networks of the railway network).

It can be found that, the CTTNs is a special network between the rule networks and the small-world networks,

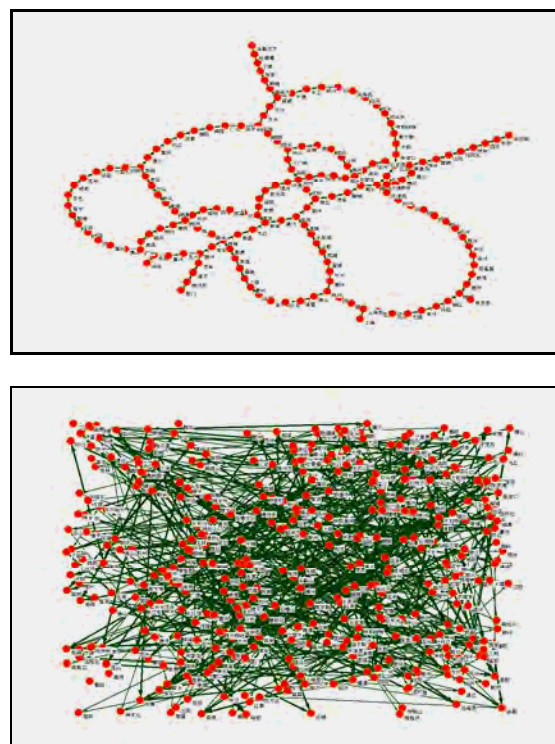


Figure 3. The topology diagram of Chinese Train Transport Networks (up) and the railway networks (down)

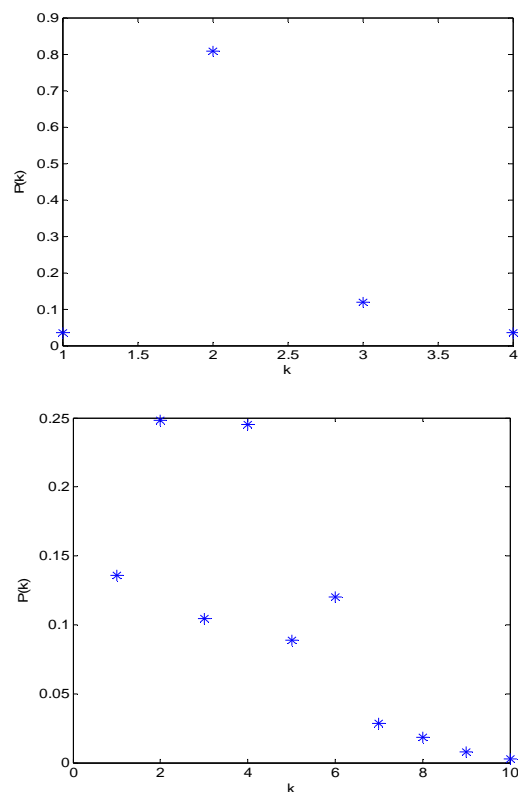


Figure 4. The degree distribution diagram of Chinese Train Transport Networks (up) and the railway networks (down)

Table 1. Basic characters of the railway networks and the CTTNs

Network Character	The CTTNs (1)	The railway networks (2)	The largest connected sub-set of (2)
The total number of nodes N , edges L	168 nodes, 532 lines	385 nodes, 1379 lines	373 nodes, 1351 lines
Diameter D	37.	31.	31.
Characteristic path length CPL	15.00143	13.17240	13.17444
Average clustering coefficients C	0.0357	0.2176	0.2126
degree-degree assortativity coefficients r	0.0245	0.0534	0.0652
Global efficiency E	0.1045	≈0.1078	0.1078
Betweenness centralization B_n	0.28463	0.31195	0.33143
Closeness centralization C_c	0.05778	\	0.07408

and its clustering coefficient is 0.0357, the average path length is 15.00143, the network diameter is 37, the global efficiency is 0.1045, degree of correlation coefficient is 0.0245, the average betweenness is 0.28463; while the railway network's clustering coefficient is higher (0.2176), the average path length, network diameter is shorter (13.17444 and 31, respectively), the global efficiency is 0.1078, degree of correlation coefficient is positive (0.0534), the average betweenness is slightly larger (0.31195).

The 'CTTNs's clustering coefficient is far below the average clustering coefficient of the railway network', and this fact could be interpreted as: CTTNs's structure is similar to 'thin' rule network, the partly reason for this design is to 'ensure the express network have the breadth of coverage area'.

The data of **Table 1** showed that there is little difference between CTTNs's average path length and the railway network's, which can also illustrate CTTNs more complete and scientific. However, by comparing the specific value of the global efficiency, it is easy to find that the global efficiency of the existing Express network did not reach the efficiency of the railway network. This shows the network does not maximize being exploited. While the fact which can not be overlooked is that China's railway network's global efficiency is lower compared with developed countries. The reason is due to the history of the national economic planning and construction and the existing network extremely dependent on the passenger network.

2.3 Network Structure Characteristics: Robustness & Fragility

Recently, W. Zhao and some other researchers had pointed out ^[7] that, the average clustering coefficient of

the network close to zero. They believe that such rail Geo-Network is a tree-like network, which means the net-work is likely disconnected. They further pointed out that the railway system with this structure, a paralysis of a particular site may result the global system disruption.

This paper established railway network and the CTTNs, the two networks have lower average clustering coefficient, but still much greater than the same size of random network. The node betweenness of the two networks were 0.28463 (CTTNs) and 0.31195 (railway network), and this means the express network have more tolerant of line fault occurs than the railway network, that is, the CTTNs has a certain robustness. These two types of network can not be overlooked fragility because they have higher mean betweenness.

3 "Betweenness + Efficiency" Combinatorial Method Research -- Take the Optimization of the CTTNs as an Example

In order to improve the efficiency of CTTNs, designers can take full advantage of the existing transport network to increase some operating sites and lines; they can also establish new operational sites and lines based on the long-term planning of China's railway construction, and gradually improve the operational efficiency and safety of the railway network and the Express network. In general, by calculating the key characteristics of the transformation network and comparing with the existing Express network, we can make some of the more practical construction and development strategy. That is, based on the existing transport network line's distribution and structure, from the point of larger node betweenness's operating sites, add appropriate new express line and site operations, and gradually increase the efficiency of CTTNs.

By definition, node betweenness of transport network can reflect the importance of the node (Express site), generally, the bigger of the node betweenness, the more "shortest path" that across the node, the node have a "transportation hub" effect in the network. Link betweenness of transport network can reflect the importance of the link (Express route), the link play a "bridge" role in the network.

By calculating: the pre-23 sites which node betweenness is the biggest are Fuyang, Shangqiu, Haozhou, Xiangtang, Hengshui, Bazhou, Macheng, Huangchuan, Heze, Liaocheng, Jiujiang, Nanchang, Baoji, Beijing, Hua Shan, Xi'an, Zhengzhou, Beijing South, Xianyang, Ji'an, Ganzhou, Zhuzhou, Tianjin West.

Taking the 23 largest sites above-mentioned as the key points, we can try to expand the network. Further, we can calculate the characteristics of the network, and give some preliminary effective strategies to improve the network structure. For example, calculate the global effi-

ciency of the network, if the efficiency of the Express Network increased, then add this line as the Chinese train transport route; calculate the global clustering coefficients, if the clustering coefficients of the Express Network increased, then add this line as the Chinese train transport route. This will ensure a better connectivity of the network.

Usually, we can analysis the global efficiency. Adding the following few routes, analysis the feasibility of opening the relevant express line. **Table 2** shows the change of the specific characteristics of the case.

Through careful calculation, we can see all the suggested lines added by our method can improve the global efficiency of existed PTTNs. Add a single line leading the global efficiencies up to 4.69%, and if integrated the six lines will leading the global efficiency up to 15%. This research can be referred by experts majored in such typical fields.

4 Conclusions

As one of the important parts of the railway network, the Express network is directly related to the steady increase of healthy operation of the national economy and people's living standard. From the perspective of complex networks, the analysis about the network of railway operations related to efficiency, safety and other aspects , is a novel transport network analysis and research method

and has a very important basic theoretical significance and a potential application value.

This article from complex network analysis perspective, proposes the "Betweenness + Efficiency" combinatorial method, which is used to optimize the transport network planning study. Using CTTNs in order to optimize the expansion of the network transformation analysis as an example, this article describes the feasibility and superiority of proposing the analysis method. This paper not only analyzes the basic characteristics of such networks, and reveals that the existing rail network and the CTTNs is a special class of artificial networks between the regular networks and the small-world networks; but also further proposes the "Betweenness + Efficiency" combinatorial method to guide operational planning and construction of the network. Numerical studies have shown that the program proposed in this paper will enable that the operations network transformed obtains a certain increase of overall efficiency. Especially the transformation strategy of the merger of more than one added line is able to express the overall efficiency of the network significantly. This paper's findings undoubtedly have an important reference value for the further optimizing planning and construction of express network in China. Certainly, the result of this study is just the initial exploration for such a real problem, and need further in-depth refinement. It should be pointed out that for the

Table 2. The change of the specific characteristics of different cases

Specific additional lines	(E\Δ)	r	D	CPL	C	Bn	Cn
The CTTNs (not add any new lines)	0.1045 ↑ 0.0000	r=0.0245	37	15.00143.	0.0357	0.28463	0.05778
Jiujiang-Huangshi-Wuchang-Hanyang-Changjiangbu-Suizhou-Xiangfan-Danjiang-Shiyan-Ankang-Xi'an	E=0.1050 ↑ Δ=0.0048	r=0.0052	37	14.73188 ↓	0.0341 ↓	0.25145↓	0.05663
Heze-Xinxiang-Jiaozuo-Yueshan-Houma-Xi'an	E=0.1066 ↑ Δ=0.0201	r=0.0672	36 ↓	14.69112 ↓	0.0353 ↓	0.27582↓	0.05769
Hefei-Huangchuan-Xinyang-Nanyang-Baofeng-Xi'an	E=0.1092 ↑ Δ=0.045	r=0.0798	36 ↓	14.12899 ↓	0.0353 ↓	0.37409	0.06940 ↑
Litang-Liuzhou-Huaihua-Gushou-Zhangjiajie-himenxian-Zhicheng-Jingmen-Xuancheng-Xiangfan-Nanyang-Baofeng-Luoyang-Yueshan-Changzhabei- Yuci	E=0.1094 ↑ Δ=0.0469	r=-0.0026 <0	33 ↓	13.74791 ↓	0.0335 ↓	0.20819↓	0.05534
Huaihua - Chongqing - Suining - Chengdu	E=0.1054 ↑ Δ=0.0086	r=-0.0038 <0	37	14.85221 ↓	0.0355 ↓	0.25914 ↓	0.05598
Chongqing - Dazhou - Ankang - Xi'an	E=0.1064 ↑ Δ=0.0182	r=0.0169	35 ↓	14.51257 ↓	0.0353 ↓	0.25188 ↓	0.06051 ↑
Integrated six suggested lines	E =0.1198 ↑ Δ=0.1464	r =0.1189	30 ↓	12.01199 ↓	0.0317 ↓	0.25345 ↓	0.07780 ↑

Remark 1: The calculations of the network's efficiency after adding some new lines, are all based on the original network after adding a single new line.

Remark 2: 'the relative changes value of the network's global efficiency' is defined as: $\Delta = \frac{E_{New} - E_{cnTrainTransport}}{E_{cnTrainTransport}}$, E_{New} , $E_{cnTrainTransport}$ represent the efficiency of the new and the original Express Network respectively. "↑" represents the increase of index value, "↓" represents the reduction of index value.

E\Δ- Global efficiency(rate of change), r- Degree-degr assortativity coefficients, D- Diameter, CPL- Characteristic path length, C- Average clustering coefficients, Bn- Betweenness centralization, Cn- Closeness centralization

lack of more detailed data, the study of the paper have some obvious deficiencies in following aspects: first, this object of study is the CTTNs, which has a simple network structure, strong characteristics of the artificial networks. The network operational efficiency analysis, optimization to improve strategies, and the “betweenness” analysis, is inevitable with a strong “artificial enumeration” features. That is not enough scientific reasonable. Second, when it verifies the network is whether to improve transport efficiency or not by analyzing the features of the original network, it fails to analysis comprehensively to obtain the corresponding changes in other digital features. Finally, the improve analysis about operating network remains at the theoretical level because of the lack of some important factors analysis and related data. This paper merely analyzes the simple case that the physical network’s sites and sides all have no right and undirected, and do not have detailed analysis about the objective existence of the real line, the site capacity constraint limits and other factors. The three aspects mentioned above need to be further studied, when we get more relevant data, use related analysis methods of “empowerment, directed” complex transportation net-

work, which will be considered in our next study.

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