A Study on the Operational Efficiency and Risk of the High-speed Rail Network in the Three Northeastern Provinces

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Abstract: With the sustained and rapid development of China's economy and society, the scale of railway construction and the quality of transportation services have been significantly enhanced. High-speed rail (HSR), as an important infrastructure and a major livelihood project, has seen rapid growth in its operational mileage. It has become the primary choice for national travel, greatly promoting the economic development of cities along the lines and facilitating the movement of people and goods. However, despite the adoption of a "three-in-one" security safeguard system that integrates human, material, and technological defenses, the HSR system is still vulnerable to losing some of its service capabilities under the impact of terrorist attacks, natural disasters, and other unexpected events, causing significant direct or indirect social and economic losses. This paper takes the HSR network in the three Northeastern provinces as the research object and analyzes its operational efficiency and vulnerability risks by combining complex network theory, with the aim of providing references for its optimization.

***Keywords*:** logistics network,high-speed rail network,operational efficiency,vulnerability risk

1. Introduction

With the continuous expansion of high-speed rail (HSR) networks, their vulnerability has gradually become a focal point of academic research. Scholars both domestically and internationally have employed advanced methods such as complex network theory and simulation modeling to conduct in-depth studies on the performance of HSR networks when facing unexpected events like natural disasters and equipment failures[1-2]. Research has found that these unexpected events may lead to a decline or even loss of service capacity in HSR networks, posing a direct threat to the normal operation of the networks and the travel experience of passengers[3-4]. Conducting in-depth research on the vulnerability risks of HSR networks is not only crucial for ensuring their safe and stable operation but also an inevitable requirement for improving service quality and efficiency and promoting the sustainable and healthy development of the HSR industry[5-6]. In the future, as HSR networks continue to expand and improve, effective management and response to vulnerabilities will become the key to ensuring their long-term reliable operation.

2. Analysis of the Operational Efficiency of the High-Speed Rail Network in the Three Northeastern Provinces

2.1 Analysis of Average Degree

The average degree is an important indicator for measuring the connectivity of nodes in a network[7]. By analyzing the average degree of the high-speed rail network in the three Northeastern provinces, we can understand the connection status of the nodes. As shown in Figure 1, the average degree of the high-speed rail network in the three Northeastern provinces shows a year-by-year increasing trend. This indicates that as the high-speed rail network continues to improve, the connectivity between nodes is also increasing.

2.2 Analysis of Network Efficiency

Network efficiency is an important indicator for measuring the efficiency of information transmission between nodes in a network[8]. By analyzing the network efficiency of the high-speed rail network in the three Northeastern provinces, we can understand the information transmission status between nodes. The network efficiency of the high-speed rail network in the three Northeastern provinces also shows a year-by-year increasing trend. This indicates that as the high-speed rail network continues to improve, the efficiency of information transmission between nodes is also increasing.

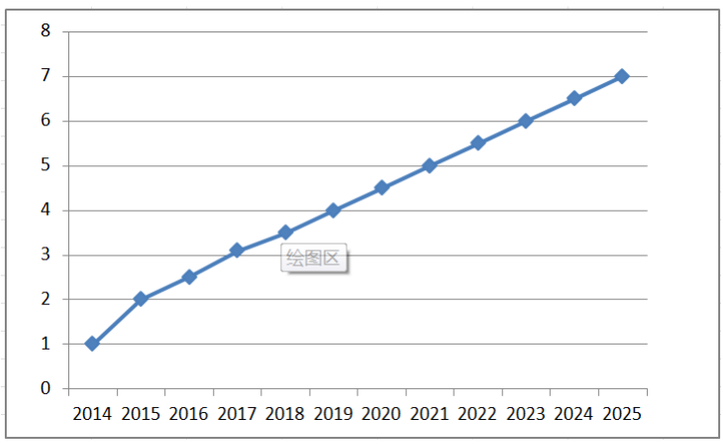

Figure 1. Changes in the Average Degree of the High-Speed Rail Network in the Three Northeastern Provinces

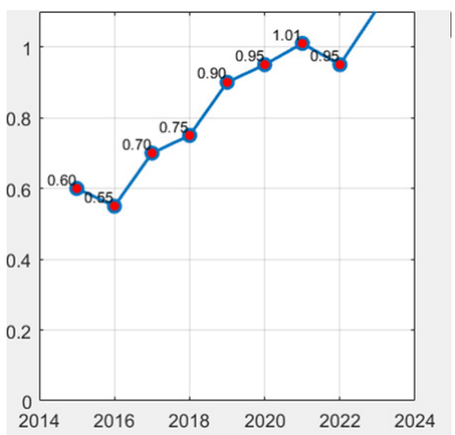

Figure 2. The network efficiency of the high-speed rail network in the three Northeastern provinces

2.3 Analysis of Average Path Length

The average path length is an important indicator for measuring the average shortest path length between nodes in a network[9]. By analyzing the average path length of the high-speed rail network in the three Northeastern provinces, we can understand the average distance between nodes. As shown in Figure 3, the average path length of the high-speed rail network in the three Northeastern provinces shows a year-by-year decreasing trend. This indicates that as the high-speed rail network continues to improve, the average distance between nodes is also decreasing.

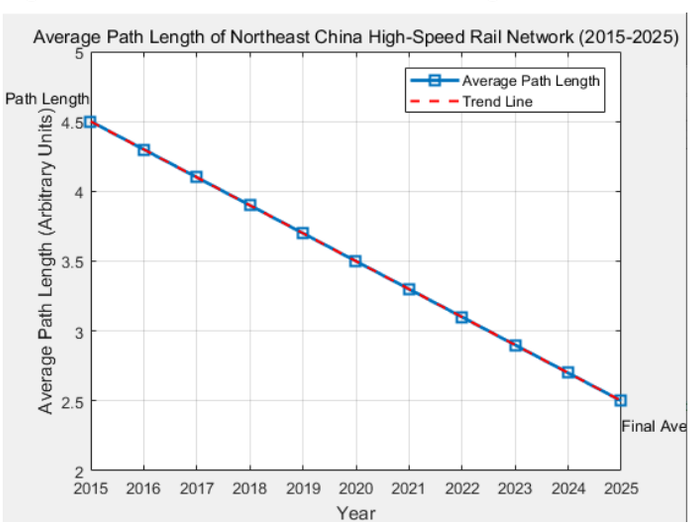

Figure 3. Changes in the Average Path Length of the High-Speed Rail Network in the Three Northeastern Provinces

3. Analysis of the Vulnerability Risks of the High-Speed Rail Network in the Three Northeastern Provinces

3.1 Degree Distribution Analysis

Degree distribution is an important indicator for measuring the distribution of node degrees in a network. By analyzing the degree distribution of the high-speed rail network in the three Northeastern provinces, we can understand the connection status and distribution characteristics of the nodes. As shown in Figure 4, the degree distribution of the high-speed rail network in the three Northeastern provinces exhibits the characteristics of a power-law distribution, that is, a few nodes have high degree values, while most nodes have low degree values. This indicates that there are some important nodes in the high-speed rail network that play significant roles.

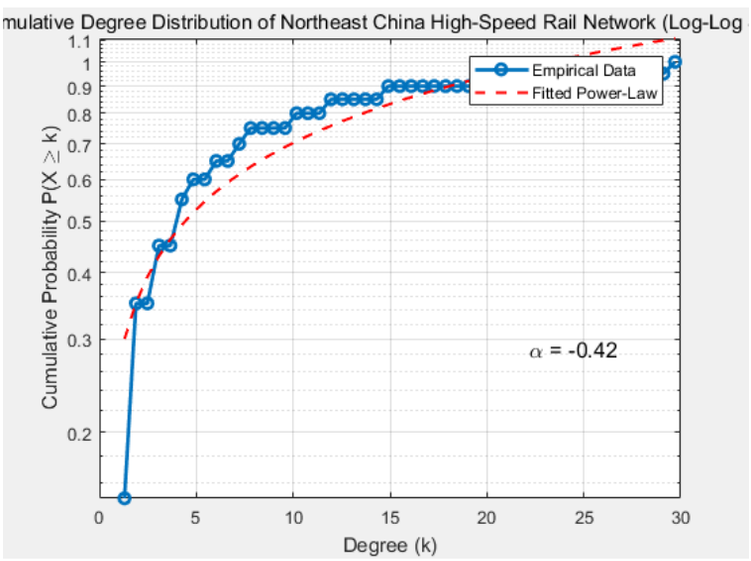

Figure 4. Degree Distribution of the High-Speed Rail Network in the Three Northeastern Provinces

3.2 Betweenness Distribution Analysis

Betweenness distribution is an important indicator for measuring the distribution of node betweenness in a network. By analyzing the betweenness distribution of the high-speed rail network in the three Northeastern provinces, we can understand the importance and distribution characteristics of the nodes. As shown in Figure 5, the betweenness distribution of the high-speed rail network in the three Northeastern provinces also exhibits the characteristics of a power-law distribution, that is, a few nodes have high betweenness values, while most nodes have low betweenness values. This indicates that there are some key nodes in the high-speed rail network that play important bridging roles.

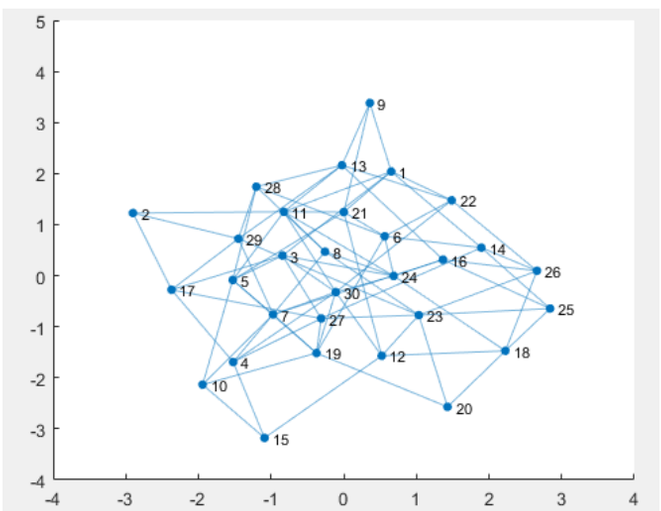

Figure 5. Betweenness Distribution of the High-Speed Rail Network in the Three Northeastern Provinces

Through the analysis of the degree distribution and betweenness distribution of the high-speed rail network in the three Northeastern provinces, we can identify some important nodes and critical routes in the network. These nodes and routes play significant roles in the high-speed rail network, and if they are attacked or fail, it may lead to the paralysis of the entire network or a decline in its service capacity. Therefore, it is necessary to focus on the protection and maintenance of these nodes and routes to reduce the vulnerability risks of the high-speed rail network.

4. Conclusion

The high-speed rail network in the three Northeastern provinces is subject to certain vulnerability risks. Through the analysis of degree distribution and betweenness distribution, we have identified some important nodes and critical routes within the network. If these nodes and routes are attacked or fail, they may have a significant impact on the overall operation of the network. Therefore, it is necessary to focus on the protection and maintenance of these nodes and routes to reduce the vulnerability risks of the high-speed rail network.

In terms of optimization recommendations for the high-speed rail network in the three Northeastern provinces, we propose measures such as strengthening node protection, optimizing route layout, enhancing emergency response capabilities, and intensifying technological research and innovation. The implementation of these measures will help further improve the operational efficiency and safety of the high-speed rail network, providing passengers with higher-quality travel services.

Acknowledgments

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References

[1] WANG shaobo, DUAN Wei, QIN Yafeng, et al. Spatial organization model and its vulnerability assessment of high-speed rail network: Taking the Yangtze River Delta as an example[J]. Resources Science, 2022, 44(5): 1079-1089.
[2] Guo J K, He Y, Hou Y J. Spatial connection and regional difference of the coastal container port shipping network of China[J]. Progress in Geography, 2018, 37(11): 1499-1509.
[3] WANG Peiyu, WER Yi, GAO Xin. The community structure and its economic convergence effect of merchandise trade network in the “Belt and Road Initiative”area[J]. World Regional Studies, 2021, 30(1): 25-36.
[4] JIAO Jingjuan, ZHANG Fangni, LIU Jian. A spatiotemporal analysis of the robustness of high-speed rail network in China[J]. Transportation Research Part D: Transport and Environment, 2020, 89: 102584.
[5] LIU Shuli, WAN Yulai, ZHANG Anming. Does China’s high-speed rail development lead to regional disparities A network perspective[J]. Transportation Research Part A: Policy and Practice, 2020, 138: 299−321.
[6] ZHANG Zhenjiang, ZHANG Yuzhao, WANG Xiaorong. Robustness analysis of railway express freight network [J]. China Safety Science Journal, 2020, 30(3): 150−156.
[7] WANG Nuo, DONG Lingling, et al. The change of global container shipping network vulnerability under intentional attack[J]. Acta Geographica Sinica, 2016, 71(2): 293-303.
[8] WU Di, WANG Nuo, YU Anqi, et al. Vulnerability and risk management in the maritime silk road container shipping network [J]. Acta Geographica Sinica. 2018, 73 (6): 1133-1148.
[9] LU Qingchang, XU Xin, XU Biao, et al. Vulnerability research of rail transit network under bus connection scenarios[J].China Safety Science Journal,2021, 31 (8):141-146.