



Study on the Spatiotemporal Evolution of Highway Passenger Transport Network Structure Characteristics Based on Social Network Analysis Method

—A Case Study of Longgang City, Pingyang County, and Cangnan County in Zhejiang Province

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Abstract

Currently, Pingyang County, Cangnan County, and Longgang City are promoting the integrated development of the three regions. Against this background, the transportation system, especially the highway passenger transport network, serves as an infrastructure carrier that connects different regions and facilitates the flow of factors. Its structural characteristics and operational efficiency directly affect the realization degree and development quality of regional integration. Taking Longgang City, Pingyang County, and Cangnan County in Zhejiang Province as the research area, this study utilizes highway passenger transport schedule data from 2020 and 2025, and applies social network analysis method, including network density, node centrality, and node connection strength, to investigate the spatiotemporal evolution of the structural characteristics of the highway passenger transport network among these three regions. The findings are as follows: 1) In terms of passenger transport network density, the density of the highway passenger transport network in 2025 was 22.23, which was higher than 16.67 in 2020. The passenger transport connection strength of the highway passenger transport network in 2025 was enhanced, indicating that the connections between nodes have become closer and the overall level of transportation integration of the highway passenger transport network has been improved. 2) From the perspective of passenger transport connection strength between nodes, the number of node pairs with strong passenger transport connections in 2025 was greater than that in 2020, while the number of node pairs with weak passenger transport connections was

less than that in 2020. This suggests that the level of transportation integration based on the highway passenger transport network is gradually improving. 3) Regarding node centrality, from 2020 to 2025, the number of first-level nodes and second-level nodes remained stable, the number of third-level nodes increased by 5, and the number of fourth-level nodes and fifth-level nodes decreased by 1 and 4 respectively.

Subject Areas

Geography

Keywords

Social Network Analysis, Highway Passenger Transport Network, Structural Characteristics, Spatiotemporal Evolution

1. Introduction

Pingyang County, Cangnan County, and Longgang City are located in the southeastern part of Zhejiang Province and are important components of the southern sub-center of the Wenzhou Metropolitan Area. The process of regional integration in this area is not only related to the local economic and social development but also has a profound impact on promoting the construction of the southern sub-center of Wenzhou. Against this background, the transportation system, especially the highway passenger transport network, serves as an infrastructure carrier connecting different regions and facilitating the flow of factors. Its structural characteristics and operational efficiency directly affect the realization degree and development quality of regional integration.

For a long time, highway passenger transport has played an irreplaceable role in the travel of urban and rural residents, commercial exchanges, and social interactions. Particularly in travel scenarios with multiple nodes, high frequency, and short-to-medium distances, the highway passenger transport system exhibits strong flexibility and accessibility, making it an important link supporting the daily functional connections of the region. By analyzing the highway passenger transport schedules, routes, and their spatial organization, we can not only reveal the actual flow directions of passenger flow, logistics, and even information flow but also reflect the tightness and coordination of the internal structure of the region from the perspective of spatial interaction. Therefore, the highway passenger transport network is not only an important research object in transportation geography but also a powerful tool for regional spatial analysis and planning decisions.

The social network analysis method provides strong methodological support for studying the structural characteristics of highway passenger transport networks at the meso-micro spatial scale. This method regards towns as nodes in the network and passenger transport schedules as connection relationships. With the

help of centrality, network density, and connection strength, it can quantitatively identify key hubs, evaluate the overall cohesion of the network, and assess the level of regional integration. This study takes Pingyang County, Cangnan County, and Longgang City as the research area, based on highway passenger transport schedule data from two time sections (2020 and 2025), and uses the social network analysis method to analyze the spatiotemporal evolution law of the structural characteristics of the regional highway passenger transport network from three dimensions: node centrality, network density, and connection strength.

2. Research Data

2.1. Research Data Sources

The highway passenger transport schedule data are obtained from the official websites of the transportation industry management departments of Pingyang County, Cangnan County, and Longgang City, as well as the official WeChat public accounts of the public transportation companies in these three regions, where bus routes and operation schedules are published. All the above data are released by official government platforms, which ensures the accuracy of the data. To eliminate the impact of varying month lengths on data comparability, this study first calculated the average daily frequency for each node pair in each month of 2020 and 2025. The arithmetic mean of these 12 monthly average daily frequencies was then computed to derive the ‘Annual Average Daily Frequency’ for each node pair in 2020 and 2025, which was used to represent the passenger transport connection strength. The process was as follows: First, the average daily frequency for each node pair per month was calculated.

For example: In January 2020 (31 days), the total frequency from Node A to Node B was 310 trips. Thus, the average daily frequency for January was $310/31 = 10$ trips/day.

Finally, the ‘Annual Average Daily Frequency’ for each node pair was calculated as:

$$\text{Annual Average Daily Frequency} = (\text{Average Daily Frequency in January} + \text{Average Daily Frequency in February} + \dots + \text{Average Daily Frequency in December}) / 12$$

2.2. Data Processing

During the data acquisition process, if a node has multiple stations, the passenger transport schedule data of these multiple stations are merged and treated as the passenger transport schedule data of a single station. This approach serves to strengthen the node’s network centrality. The merger of stations leads to a higher total passenger frequency, resulting in a greater perceived scale of its external links. If a bus route passes through two or more other nodes, the route is split into multiple routes. For example, if a bus route runs from Location A to Location D and passes through Location B and Location C, this route is split into six routes: A-B, A-C, A-D, B-C, B-D, and C-D. If there is no direct route between two nodes

or a transfer is required, the value of passenger transport schedules is assigned [1].

The weight of edges in the passenger transport network is derived from the number of passenger transport schedules between nodes. During the data acquisition and processing, it is found that the number of schedules in the upward and downward directions of each bus route is the same. Therefore, the passenger transport network matrix constructed in this study is an adjacent symmetric undirected weighted network [2].

3. Research Methods

3.1. Network Density

Network density is the ratio of the total number of actual relationships existing in the network to the theoretical maximum number of possible relationships. It reflects the tightness of the relationships between nodes in the network and the development level of the overall network. In the study of passenger transport networks, network density represents the overall density of connections in the passenger transport network. A larger value of D indicates a closer connection degree of the passenger transport network [3]. The formula is as follows:

$$D = \frac{\sum_{i=1}^n \sum_{j=1}^n F(i, j)}{n(n-1)}$$

In the formula, D is the passenger transport network density, n is the number of nodes in the research area, and $F(i, j)$ is the number of passenger transport schedules between node i and node j . In the study of passenger transport networks, $F(i, j)$ specifically refers to the passenger transport connection strength between node i and node j . A larger value of D indicates a closer overall connection of the passenger transport network and a higher level of overall transportation integration of the passenger transport network.

3.2. Passenger Transport Connection Strength

The daily passenger transport schedules between two nodes represent the passenger transport connection strength between them. The direction of passenger transport connection between two nodes includes upward and downward directions. Therefore, the number of passenger transport schedules between two nodes is the sum of the upward schedules and downward schedules [4]. The formula is as follows:

$$F(i, j) = F(j, i) = f_{i \rightarrow j} + f_{j \rightarrow i}$$

In the formula, $F(i, j)$ is the number of passenger transport schedules between node i and node j ; $f_{i \rightarrow j}$ is the number of upward schedules from node i to node j and $f_{j \rightarrow i}$ is the number of downward schedules from node j to node i . Since the number of schedules in the upward and downward directions of each bus route is the same, $f_{i \rightarrow j} = f_{j \rightarrow i}$. A larger value of $F(i, j)$ indicates a higher passenger transport connection strength between node i and node j and a higher level

of transportation integration.

3.3. Node Centrality

Node centrality represents the central strength of a node in the network. A larger value of node centrality indicates a stronger centrality of the node in the network [5]. The formula is as follows:

$$CD(i) = \sum_{j=1}^n F(i, j)$$

In the study of passenger transport networks, node centrality is represented by the sum of the passenger transport connection strengths between the node and other nodes, and n is the number of nodes in the research area. A larger value of $CD(i)$ indicates a higher centrality of the node.

3.4. Jenks Natural Breaks Classification Method

The Natural Breaks Classification (Jenks) method identifies intervals based on the inherent natural groupings within the data. It optimally classifies similar values by minimizing variance within classes and maximizing variance between them. This method partitions features into distinct categories by setting class boundaries at points where the data exhibits the greatest differences. Intensive passenger transport connections—meaning frequent services—directly lower residents' travel costs, including wait times and opportunity costs, thereby breaking down spatial barriers across the region. This effect is highly consistent with the fundamental goals of transport integration: improving both 'accessibility' and 'mobility'.

This study uses the Jenks Natural Breaks Classification Method to divide the passenger transport connection strength between two nodes into five levels, namely strong passenger transport connection strength, relatively strong passenger transport connection strength, moderate passenger transport connection strength, relatively weak passenger transport connection strength, and weak passenger transport connection strength. These five levels of passenger transport connection strength correspond to high-level transportation integration, relatively high-level transportation integration, moderate transportation integration, relatively low-level transportation integration, and low-level transportation integration respectively.

The node scale is characterized by the centrality of the node, and the node scale is divided into five levels from high to low: first-level node, second-level node, third-level node, fourth-level node, and fifth-level node.

4. Research Analysis

4.1. Spatiotemporal Evolution of Network Density

As shown in **Table 1**, the density of the highway passenger transport network in 2025 was 22.23, while that in 2020 was 16.67, an increase of 5.6 from 2020 to 2025. This indicates that from the perspective of the overall highway passenger

transport network, compared with 2020, the passenger transport connection strength of the highway passenger transport network in 2025 was enhanced, which means the connections between nodes have become closer and the overall level of transportation integration of the highway passenger transport network has been improved.

Table 1. Statistics of density and passenger transport connection strength of highway passenger transport network in 2020 and 2025.

	2020	2020	2025	2025
Overall Network Density	16.67		22.23	
Passenger transport connection strength between node pairs and transportation integration level	(Quantity)	(Proportion)	(Quantity)	(Proportion)
Strong passenger transport connection (149 - 730): High-level transportation integration	17 (pairs)	20.0%	30 (pairs)	28.0%
Relatively strong passenger transport connection (81 - 148): Relatively high-level transportation integration	22 (pairs)	25.9%	16 (pairs)	15.0%
Moderate passenger transport connection (37 - 80): Moderate transportation integration	23 (pairs)	27.1%	30 (pairs)	28.0%
Relatively weak passenger transport connection (11 - 36): Relatively low-level transportation integration	19 (pairs)	22.4%	12 (pairs)	11.2%
Weak passenger transport connection (4 - 10): Low-level transportation integration	4 (pairs)	4.7%	19 (pairs)	17.8%
Total	85 (pairs)	100%	107 (pairs)	100%

4.2. Spatiotemporal Evolution of Passenger Transport Connection Strength

As shown in **Table 1** above, in terms of the number of passenger transport connection strength levels, 85 pairs of nodes had direct passenger transport routes in 2020, while 107 pairs of nodes had direct passenger transport routes in 2025, an increase of 22 pairs from 2020 to 2025. In 2025, the number of node pairs with strong passenger transport connections increased from 17 pairs in 2020 to 30 pairs, and their proportion increased from 20% in 2020 to 28%.

In 2025, the number of node pairs with relatively strong passenger transport connections was 16 pairs, a decrease of 6 pairs compared with 2020, accounting for 15%, which was lower than 25.9% in 2020. This is because the passenger transport connection strength of some nodes has been upgraded from the relatively strong level to the strong level.

In 2025, the number of node pairs with moderate passenger transport connections increased from 23 pairs in 2020 to 30 pairs, an increase of 7 pairs. The number of node pairs with relatively weak passenger transport connections decreased from 19 pairs in 2020 to 12 pairs, a decrease of 7 pairs, and the proportion of node pairs with relatively weak passenger transport connections dropped to 11.2%. The reason for this “one increase and one decrease” is the same as mentioned above—the passenger transport connection strength of some nodes has been upgraded from the relatively weak level to the moderate level.

Overall, the increase in the density of the highway passenger transport network and the growth in the number of node pairs with strong passenger transport connections together indicate that the level of transportation integration based on the highway passenger transport network in the Aojiang River Basin is gradually improving.

As shown in **Figure 1** below, from the perspective of the spatial distribution of passenger transport connection strength, whether in 2020 or 2025, the node pairs with relatively strong and strong passenger transport connections are mainly central node-central node and central node-adjacent node. The connection directions are distributed along the main transportation trunk lines, forming multiple passenger transport connection clusters.

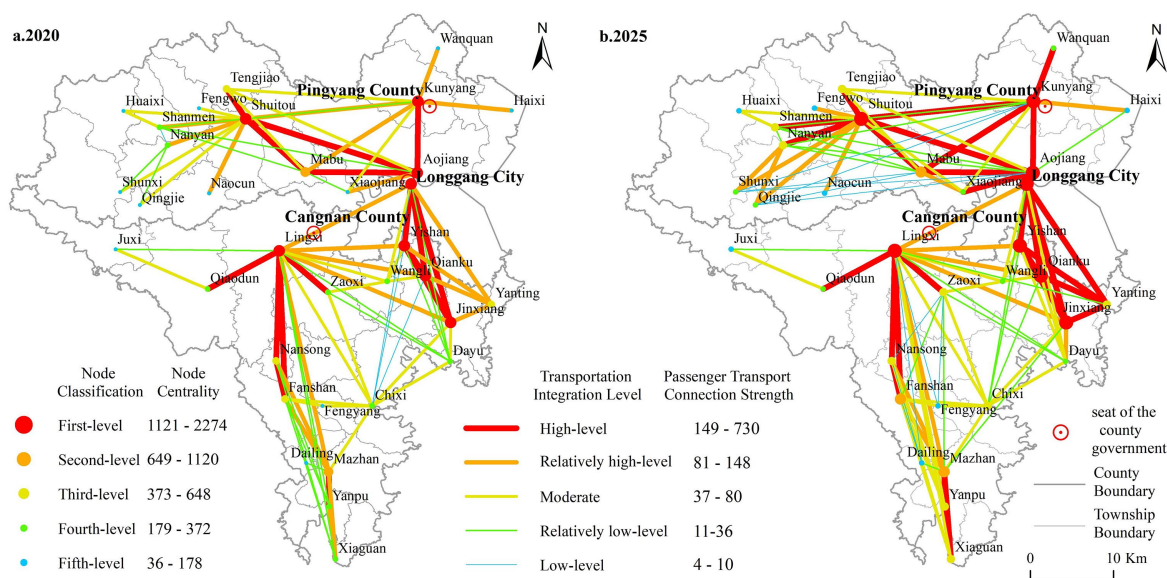


Figure 1. Node centrality and passenger transport connection intensity of the highway passenger transport network in 2020 and 2025.

4.3. Spatiotemporal Evolution of Node Centrality

As shown in **Figure 1** above and **Tables 2-4**, from 2020 to 2025, the first-level nodes and second-level nodes showed significant stability in both spatial distribution and quantity, remaining at 8 and 3 respectively. The first-level nodes are not only distributed in county seats but also include central towns such as Shuitou (Pingyang County), Aojiang (Pingyang County), and Qianku (Cangnan County), as well as economically relatively developed towns such as Yishan (Cangnan County) and Jinxiang (Cangnan County). Without exception, all first-level nodes are distributed along transportation trunk lines.

The second-level nodes include Mabou (Pingyang County), Fanshan (Cangnan County), and Mazhan (Cangnan County). Although these towns are inferior to the first-level nodes in terms of economic development and geographical location, relying on the location advantage of being close to transportation trunk lines, their passenger flow has increased significantly, making them secondary hubs connecting first-level nodes with other relatively low-level nodes.

From 2020 to 2025, the number of fourth-level and fifth-level nodes showed a downward trend. Some nodes were upgraded to third-level nodes, which led to a corresponding increase in the number of third-level nodes. Most of the lower-level nodes are geographically distributed near the county boundaries. At the same time, during this period, local governments actively promoted the development of urban-rural passenger transport integration, and the intra-county passenger transport network was further optimized. The passenger transport routes connecting first-level, second-level nodes with fourth-level, fifth-level nodes were opened one after another. This not only enhanced the passenger transport connection strength between higher-level nodes and lower-level nodes but also correspondingly improved the centrality of lower-level nodes.

Table 2. Statistics of node centrality of highway passenger transport network in 2020 and 2025.

Node Classification (Centrality)	2020 (Quantity)	2020 (Proportion)	2025 (Quantity)	2025 (Proportion)
First-level nodes (1121-2274)	8	23.5%	8	23.5%
Second-level nodes (649-1120)	3	8.8%	3	8.8%
Third-level nodes (373-648)	4	11.8%	9	26.5%
Fourth-level nodes (179-372)	8	23.5%	7	20.6%
Fifth-level nodes (36-178)	11	32.4%	7	20.6%
Total	34	100%	34	100%

Table 3. Classification of node centrality for each node in 2020 and 2025.

2025						2020					
No	Node	Classification	No	node	Node Classification	No	Node	Classification	No	node	Node Classification
1	Shuitou	First-level	18	Zaoxi	Third-level	1	Qianku	First-level	18	Shanmen	Fourth-level
2	Longgang	First-level	19	Chixi	Third-level	2	Shuitou	First-level	19	Zaoxi	Fourth-level
3	Aojiang	First-level	20	Tengjiao	Third-level	3	Yishan	First-level	20	Nanyan	Fourth-level
4	Qianku	First-level	21	Xiaojiang	Fourth-level	4	Longgang	First-level	21	Wangli	Fourth-level
5	Yishan	First-level	22	Dayu	Fourth-level	5	Jinxiang	First-level	22	Dayu	Fourth-level
6	Jinxiang	First-level	23	Wangli	Fourth-level	6	Aojiang	First-level	23	Qiaodun	Fourth-level
7	Lingxi	First-level	24	Shunxi	Fourth-level	7	Lingxi	First-level	24	Xiaojiang	Fifth-level
8	Kunyang	First-level	25	Wanquan	Fourth-level	8	Kunyang	First-level	25	Qingjie	Fifth-level
9	Mabu	Second-level	26	Qiaodun	Fourth-level	9	Mabu	Second-level	26	Haixi	Fifth-level
10	Mazhan	Second-level	27	Qingjie	Fourth-level	10	Mazhan	Second-level	27	Huaixi	Fifth-level
11	Fanshan	Second-level	28	Huaixi	Fifth-level	11	Fanshan	Second-level	28	Wanquan	Fifth-level
12	Yanting	Third-level	29	Haixi	Fifth-level	12	Nansong	Third-level	29	Shunxi	Fifth-level
13	Nansong	Third-level	30	Fengwo	Fifth-level	13	Yanting	Third-level	30	Naocun	Fifth-level
14	Yanpu	Third-level	31	Fengyang	Fifth-level	14	Tengjiao	Third-level	31	Fengyang	Fifth-level
15	Xiaguan	Third-level	32	Naocun	Fifth-level	15	Yanpu	Fourth-level	32	Fengwo	Fifth-level
16	Nanyan	Third-level	33	Juxi	Fifth-level	16	Xiaguan	Fourth-level	33	Juxi	Fifth-level
17	Shanmen	Third-level	34	Dailing	Fifth-level	17	Chixi	Fourth-level	34	Dailing	Fifth-level

Table 4. Centrality values of each node for 2020 and 2025.

2025						2020					
No	Node	Centrality Values	No	node	Centrality Values	No	Node	Centrality Values	No	node	Centrality Values
1	Shuitou	2274	18	Zaoxi	412	1	Qianku	1564	18	Shanmen	274
2	Longgang	2076	19	Chixi	412	2	Shuitou	1546	19	Zaoxi	274
3	Aojiang	2066	20	Tengjiao	390	3	Yishan	1544	20	Nanyan	264
4	Qianku	1984	21	Xiaojiang	348	4	Longgang	1424	21	Wangli	264
5	Yishan	1948	22	Dayu	308	5	Jinxiang	1412	22	Dayu	240
6	Jinxiang	1828	23	Wangli	276	6	Aojiang	1364	23	Qiaodun	202
7	Lingxi	1680	24	Shunxi	228	7	Lingxi	1364	24	Xiaojiang	178
8	Kunyang	1612	25	Wanquan	216	8	Kunyang	1362	25	Qingjie	128
9	Mabu	1120	26	Qiaodun	202	9	Mabu	808	26	Haixi	128
10	Mazhan	848	27	Qingjie	196	10	Mazhan	688	27	Huaixi	120
11	Fanshan	704	28	Huaixi	160	11	Fanshan	650	28	Wanquan	116
12	Yanting	648	29	Haixi	140	12	Nansong	520	29	Shunxi	112
13	Nansong	606	30	Fengwo	110	13	Yanting	480	30	Naocun	90
14	Yanpu	508	31	Fengyang	92	14	Tengjiao	410	31	Fengyang	80
15	Xiaguan	476	32	Naocun	90	15	Yanpu	372	32	Fengwo	72
16	Nanyan	456	33	Juxi	64	16	Xiaguan	340	33	Juxi	64
17	Shanmen	434	34	Dailing	36	17	Chixi	320	34	Dailing	24

5. Conclusions

Taking Longgang City, Pingyang County, and Cangnan County in Zhejiang Province as the research area, this study uses highway passenger transport schedule data from 2020 and 2025, and applies social network analysis method, including network density, node centrality, and node connection strength, to study the spatiotemporal evolution of the structural characteristics of the highway passenger transport network among these three regions. The research findings are as follows: 1) In terms of passenger transport network density, the density of the highway passenger transport network in 2025 was 22.23, which was higher than 16.67 in 2020. The passenger transport connection strength of the highway passenger transport network in 2025 was enhanced, indicating that the connections between nodes have become closer and the overall level of transportation integration of the highway passenger transport network has been improved. 2) From the perspective of passenger transport connection strength between nodes, the number of node pairs with strong passenger transport connections in 2025 was greater than that in 2020, while the number of node pairs with weak passenger transport connections was less than that in 2020, suggesting that the level of transportation integration based on the highway passenger transport network is gradually improving. 3) Regarding node centrality, from 2020 to 2025, the number of first-level

nodes and second-level nodes remained stable, the number of third-level nodes increased by 5, and the number of fourth-level nodes and fifth-level nodes decreased by 1 and 4 respectively.

This study has certain limitations that should be acknowledged. Primarily, the use of timetable frequency serves as a proxy for actual passenger volume and does not account for variations in vehicle load factors. Additionally, the data omits informal transport services, which may constitute a significant portion of the regional passenger flow. These factors could lead to an overestimation of integration strength in routes with high frequency but low occupancy, and an underestimation in areas reliant on informal transport.

Conflicts of Interest

The author declares no conflicts of interest.

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