The spatial distribution characteristics of the centrality advantage stations in Hangzhou metro planning (2005-2022)

Fang Wu 1*, Yue Zhu 2, Wei Zhu 1, Kaiqiang Wang 1, Peng Shen 1, Xin Wang 1

1Architectural Department, Zhejiang University City College, Hangzhou, Zhejiang, 310015, China
2Architectural Department, Zhejiang College of Construction, Hangzhou, Zhejiang, 311231, China
*wuf@zucc.edu.cn
*Corresponding author’s e-mail: elcroquis@126.com

Abstract. The identification of the metro's centrality advantage stations and regions is of great significance for in-depth understanding of the centrality layout of existing urban areas. This study selects all stations of the Hangzhou Metro Planning (2005-2022) as research cases. Based on the centrality of the complex network, it will study the spatial distribution characteristics of centrality advantage stations. The study found that: subway stations at each stage can be classified into four types of centrality advantages, and there are significant differences between these types, with a significance of 0.000; at the same time, the Type 1 and Type 2 of stations establish the core framework of the centrality advantages area; the gathering hot spot roughly establishes the range of the centrality advantage area distribution, which defines the boundary of the high advantage area. The transportation network advantage of the centrality advantage stations will be transformed into the TOD development advantage and potential of its surrounding area.

1. Introduction
Transit-Oriented Development, as an effective urban development method for the coordinated development of transportation and land use, has attracted the attention of many countries in the world and has carried out active practices. Since they hope to see the effect of policy implementation soon, urban managers pay more attention to the rapid construction of public transportation infrastructure to solve mobility problems, while neglecting the integration with land use to guide the sustainable and liveable development of the city[1]. The Hangzhou City Master Plan (2001-2020) (revised in 2016) states that Hangzhou must adhere to the principle of public transport priority, enhance the rail transit network density, and use this as an opportunity to implement TOD and optimize the urban form. Hangzhou urgently needs to conduct targeted research on its urban space environment to realize the coupling of the built environment and large-scale public transportation.

The centrality feature is the research focus of complex network analysis. It reflects the importance of the role played by individuals in an organization or system and provides a new perspective for studying the structural characteristics and functioning laws of real network systems [2]. Many researchers have abstracted road systems, public transport systems, subway systems, etc. into complex network models, and studied structural features [3-5], centrality features [6-7], and the relation with land use and urban economic activities [8-9]. Li Jin et al. [3], Zhang Tieyan et al. [4], and Wang Zhiru et al. [5]...
studied the complexity and scale-free characteristics of subway networks. Paolo Crucitti et al. studied eighteen cities in the world about spatial and statistical distribution characteristics of urban transportation network centrality [6]. Sergio Porta et al. studied the centrality characteristics of Barcelona’s transportation system [7]. Wang Fahui et al. studied the relationship between land use density and the transportation centrality of Baton Rouge in the United States [8]. Chen Chen et al. measured the centrality characteristics of the road network in the downtown area of Changchun and then analysed the relationship between it and the layout of the various commercial network [9]. However, it should be pointed out that the existing research is more focused on the road system, and insufficient consideration has been given to the role of the subway system in reshaping the centrality layout of existing urban areas. This study will select the Hangzhou Metro Planning (2005 -2022) as a case study. Based on the centrality of the complex network, it will study the spatial distribution characteristics of centrality advantage stations. The identification of centrality advantage stations and regions will help to make decisions based on the TOD development advantages, potentials, and differences of different sites, and provide a scientific basis for the formation of urban organic renewal strategies in the inventory optimization stage.

2. Research methods

2.1. Research objects and scope
This study selects all the stations of Hangzhou Metro Planning (2005-2022) as the research cases. The research scope covers the urban areas to which all three phases subway lines will extend, from Laoyuhang in the west, Great Jiangdong New Town in the east, Hangzhou Ring Expressway South Line in the south, and Linping in the north. The total mileage of Hangzhou planned urban rail transit network in the recent future is 423.5 km, and the third phase of subway construction is 387.8 km. As of April 2020, Hangzhou Metro has completed Metro Line 1, Metro Line 2, Metro Line 4 Phase I, and Metro Line 5 Phase I, and all of them have been in network operation (Table 1).

| Stage | Code | Include line | Num. of stations |
|-------|------|--------------|------------------|
| Phase I | 101 | Line 1, Phase I of Line 2 | 56 |
| Phase II | 201 | Line 1, Line 2, Phase I of Line 4, Line 5, Line 6 | 107 |
| Phase III | 301 | Line 1-10 | 224 |
| Phase III(ADJ) | 302 | Line 1-10, Line 3 adjustment, Line 5 adjustment, Airport Express | 237 |

2.2. Network model construction and multi-centricity evaluation method
The establishment of the subway network model uses the Space L method. This method regards subway stations as nodes. If two stations are adjacent to each other on a subway line, then they are regarded as having a connection. Indexes such as Betweenness centrality (Bc), Closeness centrality (Cc), and Degree centrality (Dc) are important indicators for measuring network centrality (Table 2).

| Indicators | Meaning |
|------------|---------|
| Betweenness centrality (Bc) | It reflects the degree to which a point lies in the middle of other "point pairs" in the network. |
| Closeness centrality (Cc) | It reflects how close a point is to all other points in the network. |
| Degree centrality (Dc) | It reflects the degree of connection between a point and other points in the network. |
2.3. Hot spot analysis
Hot spot analysis can be used to identify statistically significant spatial clusters of high values (hot spots) and low values (cold spots). The key indicators are z-score and p-value. The z score is a multiple of the standard deviation; the p-value represents the probability. The higher the positive z score, the tighter the clusters of high values (hot spots); the lower the negative z score, the tighter the clusters of low values (cold spots); if the z score is close to zero, it means that there is no obvious spatial clustering.

3. Research results

3.1. Types of centrality advantage stations
Using the systematic clustering method, all stations of the PhaseⅠof the subway were cluster analysed based on three indicators (betweenness centrality, closeness centrality, and degree centrality), and the results showed that they can be classified into four types. At the same time, the results of the analysis of variance showed that the four types had significant differences in all three indicators, with a significance of 0.000. Comparing the centrality characteristics of the four types of stations with each other (Table 3), it shows that the three centrality indicators all show a gradual decrease. Similarly, subway stations in other three planning stages all can be classified into four categories, and there are significant differences in the mean values of the three indicators among the four types.

Table 3. Types of centrality advantage stations of Hangzhou subway network

| Phase | Indicators | 1       | 2       | 3       | 4       | total   |
|-------|------------|---------|---------|---------|---------|---------|
|       | Bc         | Mean    | N       | Mean    | N       | Mean    | N       | Mean    | N       |
| PhaseI| Bc         | 62.357  | 1       | 41.524  | 16      | 25.993  | 7       | 9.432   | 32      | 21.616  | 56      |
|       | Cc         | 12.035  | 1       | 10.247  | 16      | 8.898   | 7       | 7.173   | 32      | 8.354   | 56      |
|       | Dc         | 7.273   | 1       | 3.863   | 16      | 3.636   | 7       | 3.409   | 32      | 3.636   | 56      |
| PhaseII| Bc        | 32.358  | 12      | 24.469  | 6       | 16.363  | 24      | 5.605   | 65      | 12.076  | 107     |
|       | Cc         | 9.334   | 12      | 8.568   | 6       | 9.331   | 24      | 6.793   | 65      | 7.747   | 107     |
|       | Dc         | 2.673   | 12      | 2.359   | 6       | 2.162   | 24      | 1.771   | 65      | 1.993   | 107     |
| PhaseⅢ| Bc         | 26.089  | 2       | 20.25   | 6       | 13.067  | 37      | 3.994   | 179     | 6.125   | 224     |
|       | Cc         | 9.771   | 2       | 9.054   | 6       | 8.435   | 37      | 6.849   | 179     | 7.196   | 224     |
|       | Dc         | 2.018   | 2       | 1.719   | 6       | 1.236   | 37      | 0.922   | 179     | 1.005   | 224     |
| PhaseⅢADJ| Bc    | 30.285  | 5       | 21.681  | 1       | 13.794  | 20      | 3.591   | 211     | 5.092   | 237     |
|       | Cc         | 11.862  | 5       | 10.456  | 1       | 10.016  | 20      | 7.842   | 211     | 8.121   | 237     |
|       | Dc         | 2.034   | 5       | 2.119   | 1       | 1.398   | 20      | 0.897   | 211     | 0.969   | 237     |

3.2. Spatial distribution of centrality advantage stations and hot spots
Comparing the spatial distribution of the centrality advantage stations with hot spots, it shows that:

In the Phase I, the Type 1 station only contains one station as Fengqi Road Station (B0124), and its three centrality indicators values are all the highest, which becomes the central node of the whole network. The Type 2 stations with the second-highest centrality value contain 16 stations, covering Line 1 from the Passenger Transport Centre Station (B0107) to Fengqi Road Station, and Line 2 from Qianjiang Century City Station (B0212) to Fengqi Road Station, such as West Lake Cultural Square Station (B0122), East Railway Station Station (B0119), Pengbu Station (B0118), etc. The hot spot analysis found that for the betweenness centrality, the amount and distribution of hot spots above the 90% confidence interval are very similar to Type 1 and Type 2 stations. However, Fengqi Road Station (B0124) belongs to the 95% confidence interval hotspot, while Datieguan Station (B0121) and Zhonghebei Road Station (A0217) belong to the 99% confidence interval hotspot. For the closeness centrality, hotspots above the 90% confidence interval are mainly concentrated around Fengqi Road Station, including Shentang Bridge Station (B0220), Ding’an Road Station (A0126), all stations between Qingling Road Station (A025), and Zhanongkou station (A0120) (Figure 1).
In Phase II, Type 1 stations include 12 stations. The betweenness centrality of Wulinmen Station is the highest in the whole network, and the closeness centrality of Fengqi Road Station is the highest in the whole network. The degree centralities of Qianjiang Road Station, Fengqi Road Station, Jinjiang Station, and Sanba Station are the highest in the whole network. Type 2 stations include six stations, including five stations along Line 1 from Pengbu Station to Passenger Transport Centre Station, and Qianjiang Century City Station (B0212) on Line 2. In the hot spot analysis, for the betweenness centrality, the hot spot distribution above the 90% confidence interval is very similar to the number and distribution of Type 1 and Type 2 stations. However, Sanba Station and Qianjiang Road Station, which belong to Type 1 stations, are still not hot spots. For the closeness centrality, the scope is expanded to the southeast along Line 6 based on the previous phase, including five stations from Jiangling Road Station (B0130) to Qianjiang Century City Station (B0212). With Fengqi Road Station and Qianjiang Road Station as the centre, two clusters of hot spots have been formed, both of which belong to the 99% confidence interval (Figure 1).

In Phase III, the Type 1 stations include two stations, Chengzhan Station (B0127) and Wulinmen Station. The three centrality index values of Chengzhan Station are the highest in the whole network. Type 2 stations include six stations, including Pengbu Station, Passenger Transport Centre Station, Fengqi Road Station, Yugu Road Station (B0318), Jianshe Sanlu Station (B0208), and Datieguan Station (B0121). In the hot spot analysis, for the betweenness centrality, the skeleton of the hot spot distribution is still very similar to the distribution of Type 1 and Type 2 stations, while the amount of stations is much larger than the amount of the two types of stations. The distribution of hotspots forms three clusters, one cluster is the stations around Line 1 from Wulinmen Station to Chengzhan Station, the other one is the stations along Line 1 from Datieguan Station to Gaosha Road Station (A0110), the last one is around Construct Sanlu Station. For the closeness centrality, the scope is extended to the north along Line 4 based on Phase II, including Xiwenjie Station (A0513), Shaxian Station (B0512), Jianxin Road Station (A0420), Mingshi Road Station (A0419), and so on. The two clusters in the previous period gradually joined and merged, forming a larger-scale hotspot cluster with stations all belong to a 99% confidence interval (Figure 1).

![Figure 1. Distribution of the types of centrality advantage stations in four phases](image-url)
In the Phase III adjustment, the Type 1 stations include five stations, namely East Railway Station, Shentang Bridge Station, West Lake Cultural Square Station, Yudao Station (B0916), and Wensan Road Station (BAP06). Among them, the betweenness centrality and degree centrality of East Railway Station Station are the highest in the entire network, while the closeness centrality of West Lake Cultural Square Station is the highest in the entire network. The Type 2 station includes one station. In the hot spot analysis, for the betweenness centrality, the skeleton of the hot spot distribution is consistent with the distribution of Type 1 and Type 2 stations, while the amount of stations is much larger than the amount of the two types of stations. The distribution of hot spots forms two belt-shaped corridors. One is the belt corridor from Gucui Road Station to Chengzhan Station along the Line 1, Line 2, and Line 3, and the other is the belt corridor from East Railway Station station to Xiaoshan Airport Station. For the closeness centrality, based on Phase III, its scope extends westward to Line 10, including Yugu Road Station, Wensan Road Station, Gucui Road Station, Xianing Bridge Station, and other stations, forming a larger hotspot cluster (Figure 1).

4. Conclusion

According to the classification results of the stations in the four planning stages, the stations belonging to Type 1 and Type 2 are collected and sorted, and it shows that some stations play important network roles in different planning stages (Table 4).

| Station code | Station name         | Planning stage | Station code | Station name         | Planning stage |
|--------------|----------------------|----------------|--------------|----------------------|----------------|
| B0124        | Fengqi Road          | T1*            | B0122        | West Lake Cultural Square | T2             |
| A0115        | Jiubao               | T2 T2          | B0123        | Wulin Square         | T2             |
| A0116        | Jiuhe Road           | T2 T2          | B0127        | Chengzhan            | T2 T2          |
| A0117        | Qibao                 | T2 T2          | B0129        | Jinjiang             | T1             |
| A0120        | Zhanongkou Square    | T2             | B0208        | Jianshe Sanlu        | T1             |
| A0214        | Qingchun Square      | T2             | B0212        | Qianjiang Century City | T2 T2         |
| A0215        | Qingling Road        | T2             | B0213        | Qianjiang Road       | T2 T1          |
| A0217        | Zhonghe North Road   | T2             | B0216        | Jianguo North Road   | T2             |
| A0221        | Xianing Bridge       | T1             | B0219        | Wulinmen             | T1 T2          |
| A0223        | Gucui Road           | T1             | B0220        | Shentang Bridge      | T1 T1          |
| A0224        | Fengtan Road         | T1             | B0222        | Xueyuan Road         | T1             |
| A0225        | Wenxin Road          | T1             | B0226        | Sanba                | T1             |
| B0107        | Transport Center     | T2 T2 T1       | B0318        | Yugu Road            | T1             |
| B0118        | Pengbu               | T2 T2 T1       | B0916        | Yudao                | T1             |
| B0119        | East Railway station | T2 T1 T1       | BAP06        | Wensan Road          | T1             |
| B0121        | Datieguan            | T2 T1          |              |                      |                |

*T1 means Type 1; T2 means Type 2

The first situation: stations that are Type 1 stations multiple times. The most prominent ones are Fengqi Road Station, East Railway Station Station, and Shentang Bridge Station. In the corresponding period, they played the role of the core of the network.
The second situation: stations that are Type 2 or Type 1 stations multiple times. Passenger Transport Centre Station and Pengbu Station are both in Type 2 stations in the four planning phases.

The third situation: the roles of these stations become greater in the later planning phases, which mainly include Chengzhan Station, Datieguan Station, Jianshe Sanlu Station, Yugu Road Station, Yudao Station, West Lake Cultural Square station, etc. These stations do not play an important role in the initial planning phases, but with the subway network growth, their role in the network becomes more and more important.

The fourth situation: special stations. Wensan Road Station is a new transfer station between the Airport Express Line and Line 10 in the Phase III adjustment. There is not originally this station in Line 10. In the overall subway network of the Phase III adjustment, the station has the highest type of network centrality advantage.

On this basis, combined with hotspot analysis, more stations play important roles in different phases. These stations include Ding'an Road Station, Wulin Square Station, Wulinmen Station, Xianing Bridge Station, Xueyuan Road Station, Gucui Road Station, Mingshi Road Station, Sanbao Station, Chaowang Road Station, Longxiang Bridge Station, Xiaoshan Airport Station, etc.

With the phased construction of the Hangzhou subway, the subway network has gradually evolved from a single centre to a multi-centre network system. Therefore, the area around the station has the advantages of centrality based on the subway network. Comparing the distribution of station types with hotspots, it shows that the Type 1 and Type 2 stations establish the core framework of the centrality advantage regions; while hotspots establish the centrality advantage regions range, which defines the boundary of the high dominant area. The transportation network advantage of these centrality advantage area will be transformed into the TOD advantage and potential of the surrounding area. Based on the difference of the surrounding area of these station areas, the built environment optimization renovation will greatly promote the coupling of the built environment and large-scale public transportation, and promote the urban TOD model development.

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