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Classification and Development Potential Evaluation of Urban Metro Station Areas Based on Extended Node-Place Model-- A case study of Nanjing Metro Line 1

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Abstract. In the process of changing from the extensive mode to the compact mode of the urban space development in China, metro has solved the problem of high-capacity and rapid transportation in cities. The planning of metro stations needs to be investigated in the context of station types in the process of the urban development. In the research, combined with the development examples of stations and surrounding areas along Nanjing Subway Line 1, the factors such as the classification of station types, the current development potential assessment and so on were investigated based on the extended "node-place" model. And then the scientific and reasonable optimization and adjustment strategies for stations and surrounding areas were proposed, which provides reference for the subsequent planning strategies and development and construction of metro stations and surrounding areas.

Keywords: metro station; extended "node-place" model; cluster analysis; station area classification; potential assessment.

1. Introduction

The expansion of urban space brings the dual challenges of land urbanization and traffic motorization, as well as the increasing conflict between efficient land use and traffic congestion, making the rationalization and rational development of metro a hot spot for many cities in China to solve urban problems. As an important urban transportation infrastructure, metro is crucial to the land use and spatial layout adjustment of cities, and also brings great opportunities for urban sustainable development. At present, Chinese metropolitan planning and development has entered the era of "stock optimization", and the large-capacity metro plays a pivotal role in the rapid and efficient development of megacities, and in solving the problems of urban sprawl, environmental pollution and low land use efficiency caused by "car orientation".

Nanjing, as an important central mega-city in eastern China, plays an important role as a node to drive the development of the central and western regions and to link the strategic intersection of the eastern coastal economic belt and the Yangtze River economic belt, and it is of good research significance to discuss the relevance of urban metro station development and sustainable development of the city. As the first Subway Line in Nanjing, Nanjing Subway Line 1 has been in operation for 17 years since 2005, so it has good conditions and foundation for investigating urban metro stations and urban development, station type classification and potential assessment. Therefore, combined with the development examples of stations and surrounding areas along Nanjing Subway Line 1, the factors such as the classification of station types, the current development potential assessment and so on were investigated based on the extended "node-place" model. And then the scientific and reasonable optimization and adjustment strategies for stations and surrounding areas were proposed in the research, which provides reference for the subsequent planning strategies and development and construction of metro stations and surrounding areas.

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2. Theoretical Review and Research Methodology

2.1 Theoretical background

The development of metro station is affected by many factors such as the construction and operation of the station itself, the development of surrounding land and so on. In 1993, Peter Calthorpe [1], a representative of New Urbanism, proposed a "transit-oriented development" model, TOD, to address the urban sprawl in the United States after World War II. The connotation of the TOD model has evolved since Calthorpe's proposal, from its initial definition focusing on the concept of community to its instrumental role of "transportation-led development". In the process of exploring transportation and land use, Bertolini proposed the "node-place model"[2] in 1999 as an important theoretical and analytical tool for TOD research and practice, which has been applied by planners and researchers in various countries. Bertolini pointed out that urban metro stations are not only hubs and nodes, but also form a complete station area with its surrounding functional areas, and a single study of one aspect cannot describe the station and its development well. In turn, the dual nature of the node and place of the station complement each other and jointly promote each other to achieve a positive cycle of influence. Since then, scholars have expanded and improved the node-place model proposed by Bertolini in terms of indicators, dimensions, and applications of the model, and have applied the model to transportation hubs in Switzerland, Australia, and the United States.

2.2 Research process and methodology

2.2.1 Research area

The samples selected for the research were the 27 rail stations of Nanjing Subway Line 1 and their surrounding areas. The line starts from Maigaoqiao Station in the north and goes south along the north-south axis of Nanjing's main city, turning southeast at Andesmen Station to Jiangning Dongshan District, entering Jiangning University City, and arriving at China Pharmaceutical University Station in the south. The total length of the line is 38.9 kilometers, including 27.6 kilometers of underground lines and 11.3 kilometers of elevated lines. There are 27 stations, including 16 underground stations and 11 elevated stations.

2.2.2 Research scope and data sources

In order to determine the research radius of the area around Nanjing Subway Line 1, the length of the subway line and the average parking spacing were considered in this research. Due to the nature of urban subway lines in China, the spatial spacing between subway stations is smaller than that of railroad lines, and a circle with a certain distance as the radius is usually taken as the TOD reasonable area (the reasonable walking area usually includes a distance of 5 min~15 min walk). In this research, 200 m was chosen as the research area for the station area. [3]

The data on the number of subway service lines, daily train frequency, and the number of stations reachable within 20 minutes were obtained from the Nanjing Metro website (https://wwwhttps://www. njmetro. com. cn) and the Baidu Map API open platform. The data on the number of residential employment, land area and land use development intensity in each station area were based on POI data from satellite maps and the Baidu Map API open platform, real estate network (https://nanjing https://nanjing. fang. com) and field research. POI (point of interest) data reflecting the functional mixing degree of the station area were obtained from the Baidu Map API open platform. The data on the block street density and the average distance from the station to the employment sites in the station area in the design indicators were based on street network data from the Open street map (OSM), the Baidu Map API open platform, field research and GIS geographic information processing platform software. (Table 1)

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Table 1. List of data sources of indicators

Node indicators		
Train accessibility	Number of subway service lines	https://wwwhttps://www. njmetro. com. cn Website
	Daily train frequency	https://wwwhttps://www. njmetro. com. cn Website
	Number of stations reachable within 20 minutes	https://wwwhttps://www. njmetro. com. cn Website, Baidu Map API
Bus accessibility	Number of bus stops in the station area	Baidu map, public transportation website
	Number of bus lines in the station area	Baidu map, public transportation website
Types of transportation	Railroads, buses, bicycles, airplanes, long-distance buses, taxis, etc.	Information compiled from Baidu, Google and other search platforms, and field research
Place indicators		
Related indicators of subway station areas	Residential density	POI data from the Baidu Map API open platform, the Sky map satellite map, field research, and https://nanjinghttps://nanjing. fang. com Real estate network
	Employment density	POI data from the Baidu Map API open platform, Sky Map satellite maps, field research
	Number of residential households	POI data from the Baidu Map API open platform, field research, and https://nanjinghttps://nanjing. fang. com Real estate network
	Retail, hotel and restaurant workers Number of people	POI data from the Baidu Map API open platform, field research (replaced by the number of functional facilities POI agencies)
	Number of staff in education, health, culture	POI data from the Baidu Map API open platform, field research (replaced by the

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		number of functional facilities POI agencies)
	Number of staff in public administration and services (office and productive) services)	POI data from the Baidu Map API open platform, field research (replaced by the number of functional facility POI bodies)
	Functional mixing degree	Sky map satellite map, field research
	Overall development intensity of land use	Building data calculation, field research, evaluation through various sites and total building area data from Baidu's API open platform
Design indicators		
Related indicators of the built environment and walkability	Proportion of crossroads (pcs/ha)	Street network data based on the Open street map (OSM), field research
	Block street density (m/ha)	Street network data based on the Open street map (OSM), field research
	Average distance from the station to employment sites in the station area	Street network data based on the Open street map (OSM) , POI data of Baidu Maps API open platform, field research, GIS geographic information processing platform
	Average distance from the station to the settlement in the station area	Street network data based on the Open street map (OSM), POI data from the Baidu Map API open platform, field research, GIS geographic information processing platform

2.2.3 Research indicators and methods

Urban planners often think about transportation and land use systems in different ways. The node-place model is used as an analytical tool to explore the interactions between transportation and land use in station areas in urban areas. The system of indicators underlying the model was proposed by Bertolini in his 1999 article "Spatial Development Patterns and Public Transport : The Application of an Analytical Model in the Netherlands" and applied in the research of the relationship between spatial development patterns and public transport in the Amsterdam and Utrecht agglomerations in the Netherlands. The node-place model proposed by Bertolini (1999)[2] has been extended and improved by scholars since then. The basic index system, which was proposed by Bertolini and Saeed Monajem et al. (2015) [4] to expand the indicators of station accessibility and accessibility, i.e., the influence of urban space on the value of nodes and places, was consulted. By taking into account (Guowei Lyu et al., 2016; Guowei Lyu et al., 2020) [5] [6] in

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their research to investigate the accessibility indicators of employment and residents in the TOD area of a specific subway station, based on the availability of data, the indicators such as the number of subway service lines, daily train frequency, and the number of bus stops in the station area were selected to evaluate the node value; the indicators such as residential density, employment density, functional mixing degree, and land use development intensity were selected to evaluate the place value; the indicators such as the proportion of crossroads and neighborhood road density were selected to evaluate the design value (Note: Indicators with missing values over 30% were excluded from the analysis, such as information on car and bicycle parking capacity). After determining the research indicators, the TOD area of each metro station was divided geographically according to the research scope, and the data were collected and summarized according to the current status of the station area for each indicator of TOD.

Before classifying the metro station area, a correlation analysis was conducted to explore the relationship between the 18 indicators. The analysis showed that almost all indicators were positively correlated according to the logic of the extended node-place model (except for the average distance from the station to the employment sites in the station area and the average distance from the station to the residential sites in the station area). Then, a multi-step approach was adopted to identify different types of subway stations, including the following steps. (1) In order to facilitate the comparison of indicators of different scales, the Min-max standardization method was used, i.e., the original data were linearly transformed so that the results fell in the interval [0, 1]. The conversion function formula of positive correlation index is as follows: xi*=x-min/max-min (max is the maximum value of the sample data and min is the minimum value of the sample data). The averagep distance from the station to the employment point in the station area and the average distance from the station to the residential point in the station area described the proximity to the employment and residential places, namely, the shorter the travel distance, the higher the proximity. Therefore, these two indicators need to be normalized in a different way from the positive correlation indicators, using the following transformation function formula (Suarez-Alvarez et al., 2012) [7]: xi*= max-x /max-min (max is the maximum value of the sample data and min is the minimum value of the sample data), so that the minimum value is 0 and the maximum value is 1. (2) The correlation analysis showed that there was overlap among the indicators. In order to extract the main linear uncorrelated variables in the subway station area, the principal component analysis was conducted. Principal component analysis (PCA) is a multivariate technique that extracts relevant information from interrelated quantitative dependent variables and represents them as a new set of orthogonal variables, called principal components (Jolliffe, 2002)[8] . By constructing linear combinations, correlations between multiple variables were identified and information was extracted as fully as possible. Principal component analysis (PCA) was applied to generate four uncorrelated variables with a cumulative variance explained of 83.668% and was used to replace the original dataset of 18 indicators. (3) In order to complete the station classification, the second-order cluster analysis was used to minimize the variance of the indicators within clusters and maximize it between clusters. [9] The second-order cluster analysis method was applicable to both categorical and continuous data types and was consistent with the characteristics of this dataset. The clustering process was divided into two steps. The first step was to form the pre-clusters and the second step was used to define the distance matrix, which was an input to the standard hierarchical clustering process. Two pre-clusters were merged according to the log-likelihood criterion, or if the pre-clusters led to a maximum log-likelihood reduction. The number of clusters formed in this manner was determined according to the Bayesian Information Criterion (BIC), and samples that did not fit into any other pre-cluster created a separate cluster. (4) After completing the clustering analysis, the results were graphically represented so that the node indicators were defined as the sum of all node indicators. The place indicators were defined as the sum of all place indicators; and the design indicators were defined as the sum of all design indicators before plotting the node-place-design expansion model. The three indicators were then z-transformed to obtain comparable scaling, and the results were plotted in the figure. (See Figure 1)

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3. The Classification of Station Area Types Based on the Extended "Node-place" Model

3.1 Four types of station areas

Type 3 is located on the periphery of the city and in the lower left corner of the node-place analysis system (see Figure 1). It includes the station area with the lowest node-place indicator score. Compared to Type 3, Type 2 has a relatively higher score in the node-place indicator. However, the node-place indicator scores for both types have similar characteristics and are below average, and the design indicators score for Type 2 is significantly higher than that of Type 3, meaning that the built environment and walkability of these station areas are better. Their workplaces and residences are closer to the stations and walkability scores are higher. The road network is more dense and better connected. Although Type 4 has a high node indicator score, as shown in the figure, all of which are interchange stations, the place and design indicators scores are below average. Compared to Type 1 and Type 2, Type 4 includes stations with a lower mix of functions, lower density of surrounding employment and housing, lower density of the road network, and a lower level of walkability. Type 1 has the highest the place indicator score of all clusters, indicating a high level of functional mixing degree, employment, and residential density in the station area. In addition, Type 1 has a moderately high node and design indicators score compared to all clusters, exceeding the scores of most of the station areas included in other clusters, which is also inextricably linked to its role as an interchange station in the core of the city's old town.

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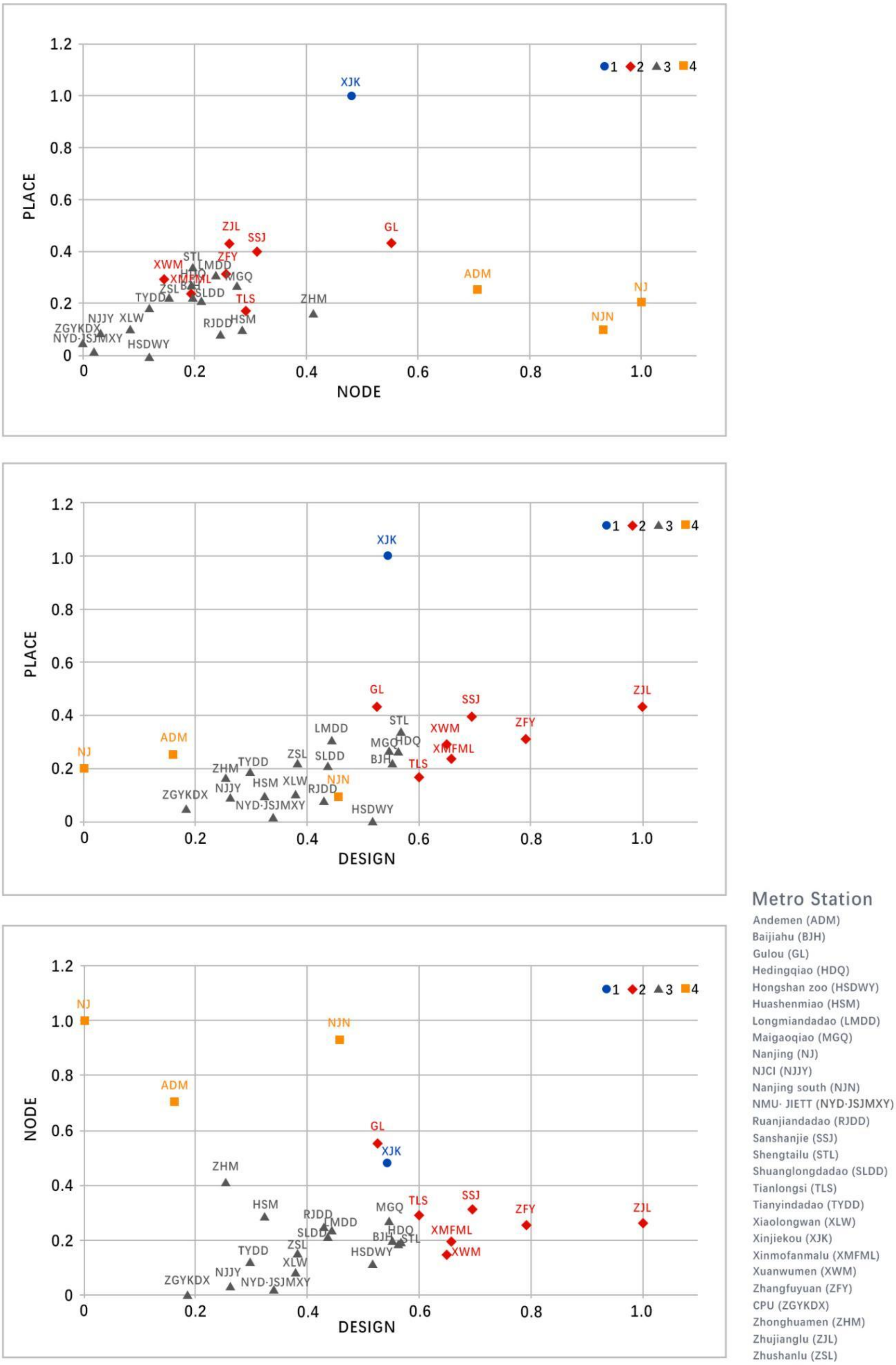

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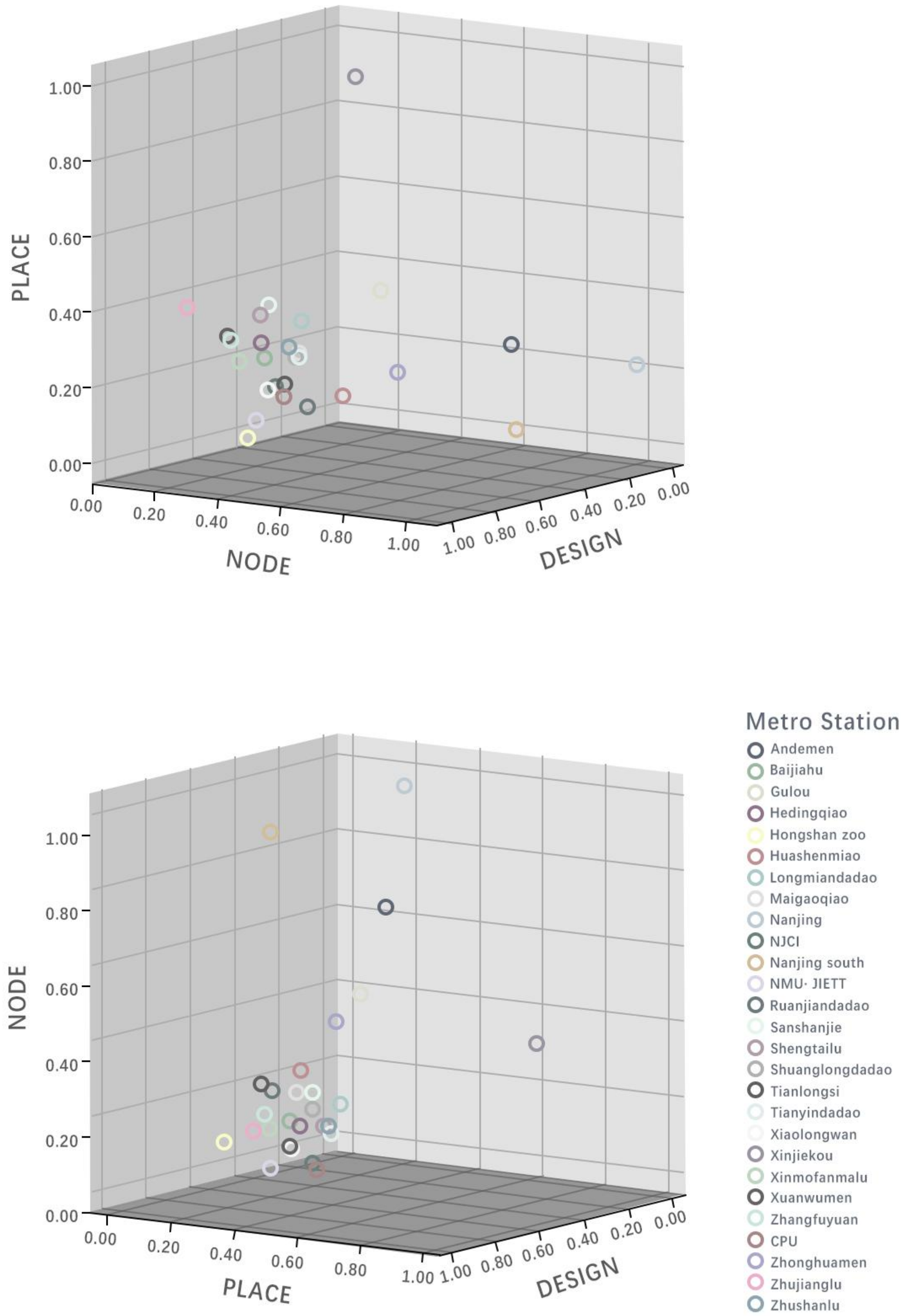

Fig. 1 Scatter plot of all station areas and four clusters in the node-place-design expansion model

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3.2 Assessment of the development potential of the station area

The similarity of station area characteristics inside clusters and the different characteristics of station areas outside clusters allow urban planners, designers and decision makers to make development strategies to the type of clusters. In this research, Type 4 has a high node indicator score as a major interchange station in the city, but a significantly lower place and design indicators score than Type 1, which is also an interchange station, indicating that Type 4 has a great potential to improve the strategy of promoting TOD in station areas, i.e., corresponding efforts should be made to increase functional mixing degreeing degree, employment density, road network density and walkability in the station area. Type 2 has a high design indicator score, and its node-place indicator scores are higher than those of Type 3 and Type 4 compared to the other clusters, which is related to the fact that Type 2 contains stations located in the main urban area (mainly the old urban areas). the old urban areas of Nanjing contains many historical areas, some of which continue the historical street network system, and some of which have narrow and dense microcirculation roads, less transit traffic, and distinctive traffic environments. The street and alley network system in the old urban areas has increased the density of the road network in the area and it is more suitable for walking in the daily travel of local residents. This also makes the station areas in the main urban area (e.g., Type 1 and Type 2) significantly more walkable than the station areas in Type 3. It also reflects that the rail stations in Type 3 have much room for development in terms of microcirculation and walkability of the station areas. The current situation of node, place and design indicators of Type 3 is significantly lower than the average of all clusters, which shows that Type 3 is different from other clusters in terms of current development level and corresponding development strategies. The station sites and areas included in Type 3 are mostly located in sub-urban areas (different from the old urban areas) and the outer urban areas. The rail station mainly reflects the characteristics of transit traffic. The land development around some stations is in the state of new construction or pending construction. The road network mainly carries the urban traffic flow, and is more of the "wide road, big block" type road network system oriented by vehicles. In addition, some stations are distributed in the university campus of education land. This makes the block scale and road network density completely different from the compact land use layout pattern of the old urban areas, such as Nanjing Medical University Station, Nanjing Jiao Yuan Station and China Pharmaceutical University Station. At the same time, some stations such as Xiaolongwan Station, Tianyin Avenue Station and Shuanglong Avenue Station are surrounded by several residential communities, which also makes the place indicator scores including functional mixing degree and other indicators much lower than those of Type 1 and Type 2. The place indicator scores, which include indicators of functional mixing degree, are not as high as those of Type 1 and Type 2. Therefore, it is necessary to develop the potential of these station areas in terms of public transportation, employment and housing, and to improve the balance of jobs and housing, strengthen the functional mixing degree of the area, and enhance the vitality of the station areas from various perspectives, such as spatial layout, land distribution and functional patterns.

The station types provide a better understanding of how investment in development for clustered stations can lead to higher overall cost benefits [5]. In this case, Type 4 does not score as high as the node indicator compared to Type 1 in terms of place and design indicators, indicating that the level of development is still low relative to the station's transportation supply and that there is a lot of untapped development potential, and that investment may lead to more effective construction outcomes. Type 2 and Type 3 still have a lot of room for potential development in the station area. Based on the logic of the node-place-design expansion model, their place indicator scores are currently well below average at the station development level.

4. Conclusion

By comparing the current development status of station areas, the relationship between station area clustering and investment, planning and construction was investigated and grasped. And the

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same logic also can be applied to solve the development of other cities with similar conditions. Combining with the case of Nanjing Subway Line 1, different key factors and indicators affecting station areas were analyzed. With the help of cluster analysis method, more targeted planning strategies were proposed for the problems and solutions of different TOD types of station areas, so that the research results can be better integrated with the planning scheme, and help researchers, decision makers and planners to conduct more accurate investigations.

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