

# Research on the Development Evaluation Method of TOD Development of Metro Station Domain

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**Abstract.** The public transport-oriented TOD model is a sustainable planning concept currently being implemented. It's in the TOD area. Most destinations can be reached directly by public transport. This emphasizes the attractiveness of public transport for residents to travel and reduces people's over-reliance on private cars, thereby improving urban problems such as diseases and traffic congestion in big cities. However, at present, the evaluation methods of TOD development effectiveness at home and abroad are insufficient in pertinence and timeliness, and can not fully evaluate the development effectiveness of TOD in orbital station area. This article takes the Beijing Metro Railway Station as an example to carry out the effective evaluation method of TOD development in the rail station domain. This paper tries to put forward a set of practical and effective evaluation methods for the development of orbital station TOD in Beijing. Therefore, it provides technical support for the further promotion of TOD development mode in the process of new city planning and old city renewal in Beijing.

**Keywords:** TOD; Railway Station; Evaluation Index System.

## 1. Introduction

In recent years, with the continuous acceleration of China's urbanization process, the population in the central area of large cities has increased and the urban functions are highly concentrated. In order to relieve stress, the central urban area has gradually developed a satellite new city to the sub-center of the city. The extension of the travel distance has gradually made private cars gradually become people's main travel tools. The problem of development. Therefore, guiding sustainable traffic is the general trend. Studies have shown that public transport-oriented TOD models can better solve this problem. In the TOD area, it can directly reach most destinations through public transport, emphasizing the attractiveness of public transportation to residents' travel, reducing people's excessive dependence on private cars, thereby improving urban problems such as large cities and traffic congestion. The TOD model has been widely promoted and applied in many large cities in my country, especially the exploration of TOD models around the rail station domain has made great progress. In this process It is of great significance to promote the scientific advancement of TOD models.

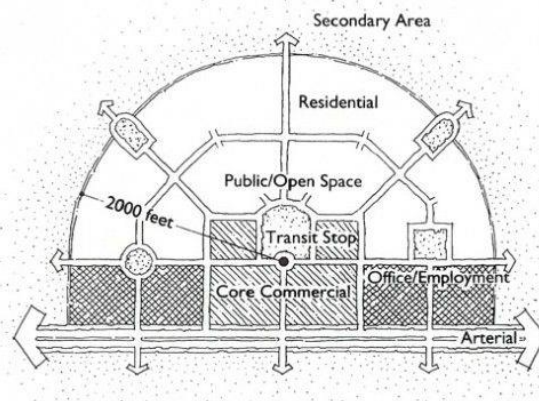
## 2. Basic Theory and Research Status of TOD Concept

### 2.1. Definition of TOD Mode

The TOD model is a planning concept that advocates moderate high-density development centered on large-capacity public transportation stations within a certain walkable range, accompanied by a mixed design of diverse land functions. The goal of TOD is to reasonably match the nature and scale



of public infrastructure in a given area. By realizing the effective integration of transportation and land, the city is guided to promote public transportation and green behavior orientation, and the land integration and functional diversification around large-capacity public transportation yards and stations are developed. The core of TOD is to coordinate the relationship between urban planning and transportation planning, and establish a multifunctional community with diverse land functions, compact regional development, convenient and accessible travel, environmental safety and vitality, and meet the needs of living, working, shopping, entertainment, travel and rest in the area around large-capacity public transportation stations. The TOD concept is shown in Fig. 1.



**Fig 1. TOD concept icon**

## 2.2. The Method of TOD Evaluation

TOD comprehensive evaluation mainly includes two types: qualitative evaluation based on TOD principle and quantitative evaluation based on establishing TOD index. Based on the concept of TOD urban development, the famous American transportation scholars Cervero and Kockelman proposed TOD's 3D planning principles of "Density, Diversity and Design", which have been widely influenced and applied. It is often used as a basis for exploring the impact of the built environment on residents' commuting or activities. However, the evaluation results are qualitative conclusions, and it is impossible to quantify the effective analysis of the effectiveness of the TOD development. The TOD index was first proposed by Evans, Jay, and others. The TOD index is used to characterize the current level of TOD development in a region. The evaluation method of TOD index is widely used. However, current research rarely evaluates the effectiveness of TOD development within rail transit stations from the perspective of travelers' travel activities, dwell activities, and transportation operation efficiency.

## 3. Beijing Railway Station Status and Development Objectives

According to the "Beijing Urban Rail Transit Construction Plan", Beijing's rail transit stations are radially divergent from the city center to the suburbs, and the downtown stations are more concentrated. From the point of view of the whole city, the development of rail lines in Beijing is not balanced.

In order to effectively respond to the national policy, Beijing has already tried the corresponding TOD in the rail station. Changyang Railway Station is the first project in Beijing to jointly develop the site and land by the same entity. At the same time, Yizhuang, Liuliqiao, Yongfeng South, Nanguan and Line 15 stations are gradually carrying out the planning and construction of station and city integration. Although there has been a clear guarantee in policy, there is still no complete planning guidance, development countermeasure support and mechanism guarantee in practice. Therefore, focusing on the development status of Beijing rail station area, the evaluation index system of Beijing rail station area development effect is established from the perspective of TOD, so as to provide theoretical guidance for guiding the spatial planning of Beijing rail station area.

## 4. Evaluation Index System of TOD Development Benefit of Railway Station Area in Beijing

### 4.1. Evaluation Method: Two-layer Evaluation Model

Based on available data, this paper proposes Two-layer evaluation model for TOD development effectiveness in Beijing. The upper layer model evaluates the population activity and travel in the station area from the perspective of TOD, including the population vitality in the station area, the traffic travel structure and the traffic travel service. The TOD development effect index of the upper layer orbital station area obtained from the evaluation results can reflect the travel situation in the orbital station area. According to the results of the upper level evaluation and the social equity index, the lower level model evaluation is carried out to obtain the TOD development effectiveness index and the final TOD development effectiveness index of the lower orbital station area.

### 4.2. Evaluation Index System Construction and Calculation Method

**Table 1.** Evaluation index system of TOD development effectiveness of Beijing railway stations

| First-level indicators                       | Second-level indicators  | Third-level indicators                       | Description  |
|--|--------------------------|--|--|
| Regional vitality                            | Vitality intensity       | Travel activity intensity                    | Total length of travel time (weekend/weekday)      |
|  |                          | Visiting activity intensity                  | Duration of visit time(Weekend/weekday)            |
|  | Diversity of activities  | Diversity of activity types                  | —  |
| Travel mode structure                        | Cycling usage            | Shared bike usage                            | —  |
|  | Public transport usage   | Public transport usage                       | —  |
|  |                          | rail transit usage                           | —  |
| Travel service                               | Accessibility            | Walking accessibility                        | Area within 10min walking distance                 |
|  |                          | Riding accessibility                         | Area within 10min riding distance                  |
|  |                          | Bus stop coverage                            | The proportion of bus service area                 |
|  |                          | Accessibility of track stations              | Number of reachable stations within 30 minutes     |
|  | Convenience              | Riding convenience                           | Average riding speed                               |
|  |                          | Convenience of rail transit                  | Average transfer walking distance of rail stations |
| Average number of transfers at rail stations |                          |  |  |
| Social equity                                | Equity of house purchase | The difference with the city's average price | —  |
|  | Residential equity       | Age mix of residents                         | —  |

In this study, 800 meters is selected as the influence radius of the railway station area. Therefore, the scope of the orbital station is a circular area with the station as the center and 800 as the radius.

The data used in this paper mainly includes the census data of Beijing's road network, rail transit network and station data, land use and building geographic information data, resident population and

employment population position data, network open source data, bus swipe card data, shared bicycle riding data, and mobile phone signaling data.

At present, the evaluation indicators of TOD development effectiveness mainly focus on land use and development, built environment, transportation, transportation facilities and services, ecological environment, and economic benefits, etc. By sorting out the TOD evaluation indicators in the study, they are further sorted out according to the four aspects of transportation, transportation facilities, built environment, and social economy. It was divided according to the five dimensions of intensity, convenience, comfort, safety and equity/inclusiveness of each aspect. In order to avoid inaccurate evaluation results due to correlation of indicators, SPSS software was used to carry out correlation analysis of all evaluation indicators, and secondary screening of indicators with high correlation was performed. The final evaluation index system was obtained according to the analysis results, as shown in Table 1.

#### 4.2.1. Upper Evaluation Indicators

a) *Vitality indicators, including the intensity of population activity and the diversity of population activity types;*

Activity intensity is the total duration of all people's activities in the orbital station area, which is calculated by the number of people and the duration of a single activity. The calculation is based on mobile phone signaling data. Take the calculation of weekend travel activity intensity index as an example, the calculation results are shown in formula 1.

$$T_{iz} = \sum_{k=1}^{n_{iz}} f(k) \quad (1)$$

Where:  $T_{iz}$  represents the activity intensity of the  $i$  site on another day;  $n_{iz}$  represents the total number of trips within the station area throughout the day.  $k$  represents the  $k$ th trip;  $f(k)$  represents the total travel time in the  $k$ th station area.

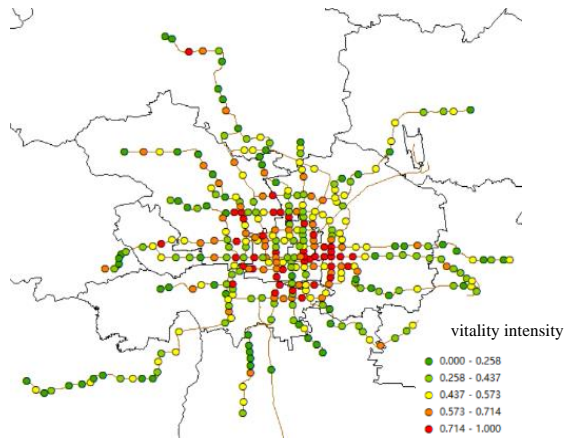
The activity intensity index, activity diversity index and final activity index of Beijing orbital station area are spatially visualized. The activity intensity index has obvious high-intensity station area, which is mainly concentrated in the orbital station area near Guomao CBD and Zhongguancun. The stations with high activity diversity of the downtown rail stations are mainly concentrated in Suzhou Street, near Haidian Huangzhuang Station, Fuxingmen, Nanlishi Road, Xidan and other stations in the east of the city center, and Chaoyangmen and Dongshix stations. The activity diversity of other rail stations has no obvious spatial characteristics, compared with the activity intensity index, The activity diversity index of track stations on suburban lines is relatively better.

According to the results of mobile signaling data, the activity diversity of residence, employment and visit within the orbital station area is calculated.

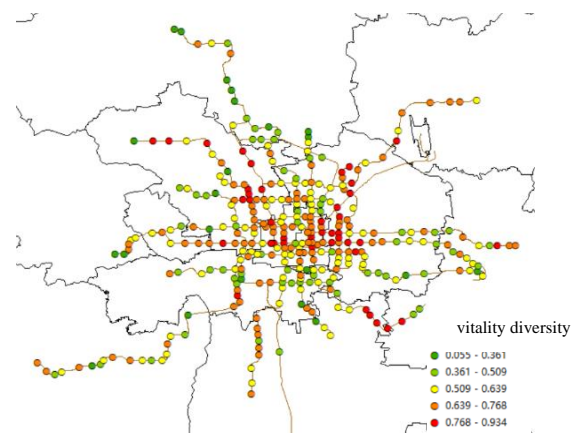
$$S_i = - \sum_{k=1}^{n_i} (p_{ik} \cdot \ln p_{ik}) / \ln n_i \quad (2)$$

Where:  $S_i$  is the diversity of activity types of site  $i$ ;  $n_i$  is the total number of types in site  $i$  (i.e. 3);  $p_{ik}$  indicates the proportion of the number of type  $k$  resident activities in the total resident visits in site domain  $i$ .

Calculation results of vitality intensity index and vitality diversity index are shown in Fig. 2 and Fig.3 respectively.

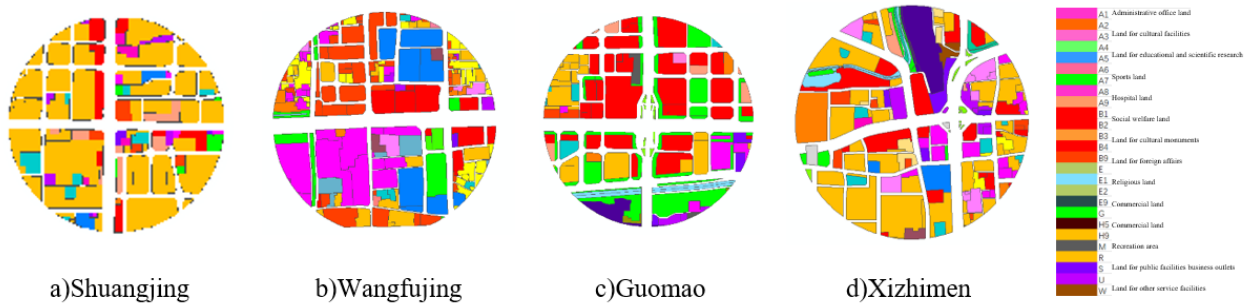


**Fig 2.** Calculation results of vitality intensity index



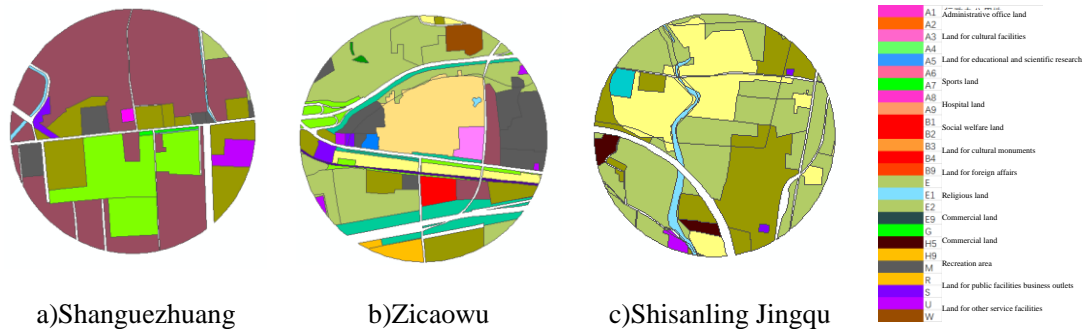
**Fig 3.** Calculation results of vitality diversity index

The high-vitality areas in the Third Ring road of Beijing are mainly distributed in large residential areas, commercial and office areas, and near urban transportation hubs, such as Shuangjing, Wangfujing, Dongdan, Jianguomen, Guomao, Beijing Railway Station, Jintai Road, etc. This area is the main center of commercial entertainment and business office activities in Beijing. Gather CBD, large shopping malls, life service facilities, business and office places, almost no non-construction land, land development and utilization has been relatively mature. Some sites with higher vitality index values are shown in Fig. 4.



**Fig 4.** Sites with higher vitality index values

The stations with low vitality index are mostly located in the suburbs of Beijing, such as Shangquezhuang Station and Ming Tombs Scenic Spot Station. There are still large areas of non-construction land and land to be further studied in the surrounding area of the above sites, and the land function of the built land is relatively simple. Some sites with lower vitality index values are shown in Fig. 5.

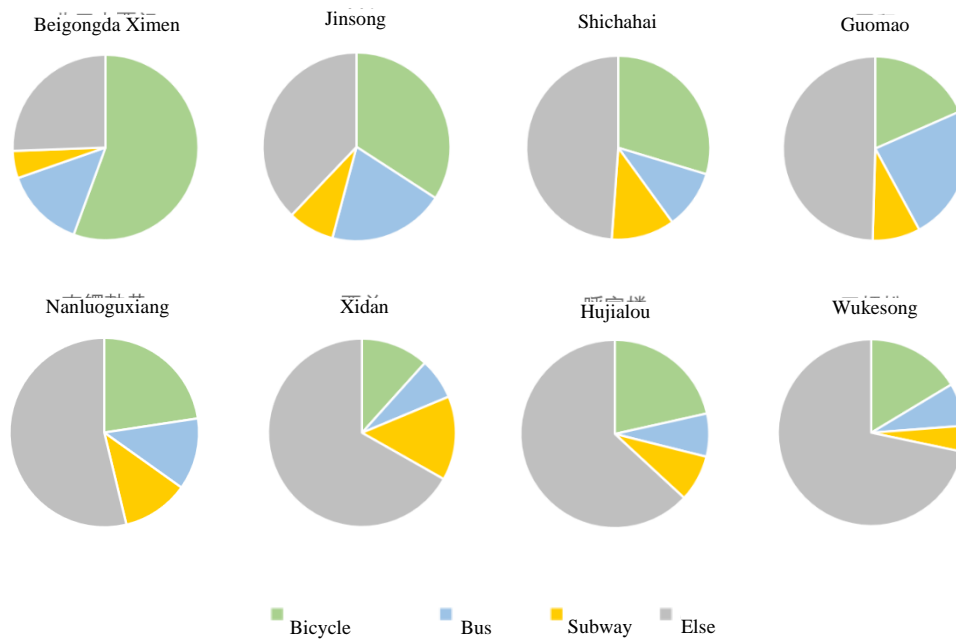


**Fig 5.** Sites with lower vitality index values

b) Traffic trip structure index, including shared bike trip sharing ratio, conventional bus trip sharing ratio, and rail transit trip sharing ratio;

Because the index is the horizontal comparison between various stations, the travel mode is simplified to the above three ways.

According to the calculation results, the sharing ratio of bicycle trips near universities (west gate of Beijing University of Technology) and scenic spots (Shichahai) will be larger, and people near bustling commercial areas (Guomao, Xidan) are more inclined to travel by subway, while those near residential areas (Jinsong, Hujialou), public service and residential sites (Wukesong) occupy a larger proportion of conventional bus and subway trips. Part of the travel mode structure of some stations are shown in Fig. 6.



**Fig 6.** Part of the travel mode structure of some stations

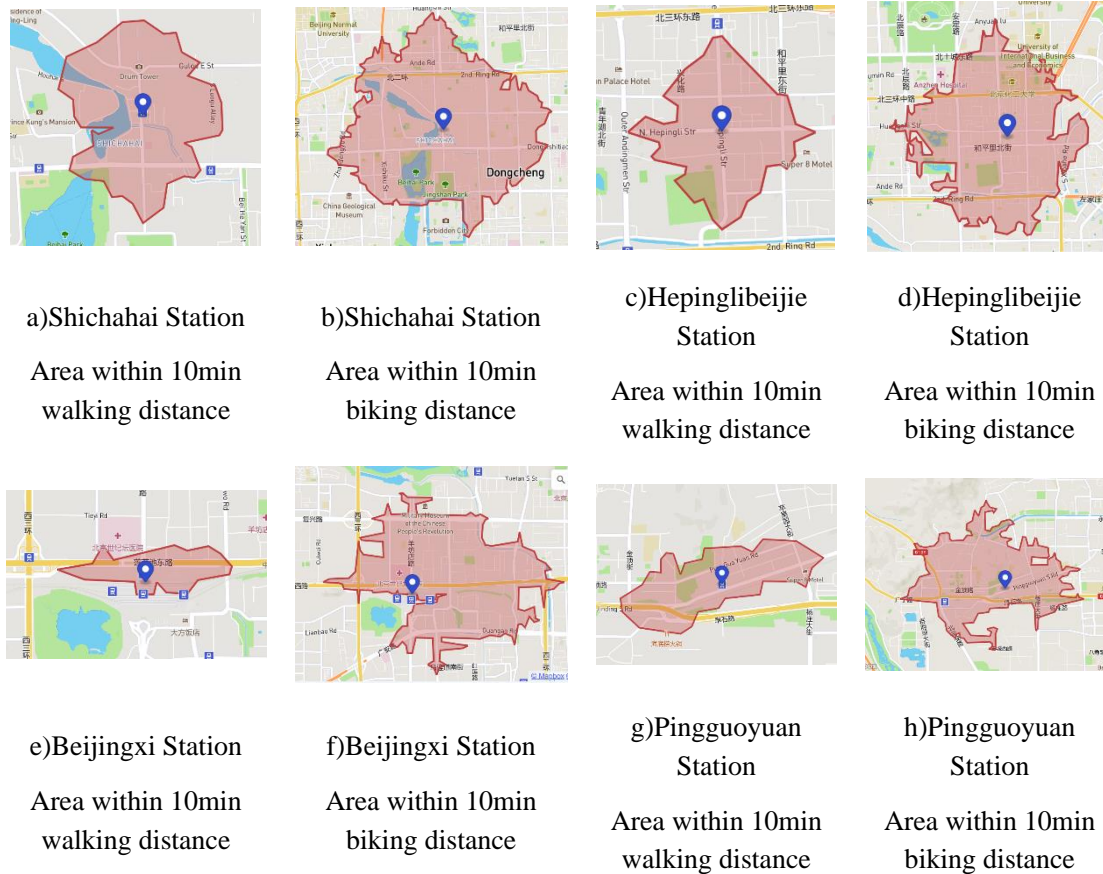
*c) Travel accessibility indicators, including the range of 10min walking from the station, the range of 10min cycling from the station, the coverage rate of public transport services and the number of 30min accessible rail transit stations;*

Walking accessibility refers to the area of the closed area that can be reached by a 10-minute walk from the track station according to the actual road network. The data is derived from Amap and calculated by Python code and Arcgis software. The calculation process of riding accessibility index is the same as above.

The bus service coverage is the total area of the 300-meter buffer zone of the bus stops in the station area. Calculated by Arcgis software.

The reachability of a track station refers to the number of other stations that the station can reach within 30 minutes.

Among them, the 10min walking accessibility and cycling accessibility of some rail transit stations in Beijing are shown in Figure 7. The above indicators are related to the road network density in the orbital station area, the number of intersections, whether there are viaducts such as expressways, the walking and cycling environment, the number of entrances and exits of the rail station and other factors. The results show that the more intersections, the more road network density, and the safer and more comfortable walking and cycling environment, the higher the accessibility index of the orbital station area. The Baliqiao, Gongzhufen and other stations are close to the viaduct, and the walking and cycling environment is inconvenient, resulting in relatively low accessibility. Dongzhimen and Guomao are also close to viaducts such as expressways, but due to the large number of entrances and exits, the coordination between public transportation and the surrounding environment is relatively smooth, so the accessibility index has not been greatly affected.



**Fig 7.** The distribution of walking and cycling accessibility results in some stations domain

*d) Travel convenience indicators, including the average speed of shared bicycles, the average number of transfers at rail transit stations and the average walking distance of transfers at rail transit stations.*

Riding convenience is represented by the average riding speed of shared bikes. The indicator can be calculated based on the average speed in the shared bike ride order.

The average transfer walking distance of the rail transit station is the average walking distance of the transfer process from the station to all other stations; The average number of transfers at a rail station is the average number of transfers from that station to all other stations.

The trend of the convenience level around the rail station is similar to that of the average number of rail transit transfers. The stations with the highest overall convenience are mainly located along Line 10, as well as the stations on Line 6 and Line 7. Most of the roads in the above station area are equipped with various forms of bicycle lanes, and the convenience index of shared bicycles is good, and the connection degree of rail transit stations is also good, so the overall convenience index is high.

#### 4.2.2. Lower Level Evaluation Indicators

*e) Equity indicators, including equity in home purchases and age diversity of residents.*

Taking the average price of second-hand housing transactions in Beijing for the whole year as the standard, the closer the average price of house purchases in the station is to the average price of house purchases in the city, the better the fairness of house purchases.

The index of residential equity is represented by the age mixing degree of residents in each station area. The age of residents in each station area is labeled in the corresponding age stage label Table 2, and the age diversity of residents is calculated according to formula (3). The greater the value of this index, the better the equity of residence.

**Table 2.** Corresponding Table of age stages

|       |       |       |       |       |       |       |           |       |
|-------|-------|-------|-------|-------|-------|-------|-----------|-------|
| age   | 0-6   | 7-12  | 13-15 | 16-18 | 19-24 | 25-29 | 30-34     | 35-39 |
| label | 1     | 2     | 3     | 4     | 5     | 6     | 7         | 8     |
| age   | 40-44 | 45-49 | 50-54 | 55-59 | 60-64 | 65-69 | (over) 70 |       |
| label | 9     | 10    | 11    | 12    | 13    | 14    | 15        |       |

$$M_i = - \sum_{a=1}^{n_i} (p_{ia} \cdot \ln p_{ia}) / \ln n_i \quad (3)$$

Where:  $M_i$  is the age diversity of the residents of site  $i$ ;  $n_i$  is the total number of age stage types in site  $i$  (i.e. 15);  $p_{ia}$  is the proportion of the number of people of type  $a$  age in the total resident population in Station  $i$ .

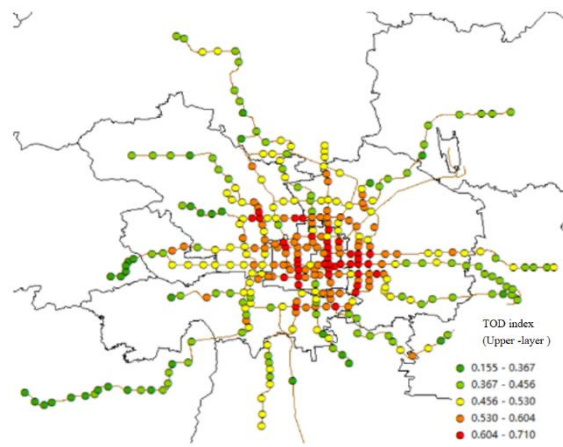
The fairness index is related to the type of land used in the orbital station area. The station area requires a certain scale of residential land, and the surrounding area is well equipped with public facilities for residents' daily life, shopping, entertainment and leisure. Xidan, Nanlishi Road, Chaoyangmen and other stations have rich land types, which can not only provide accommodation, but also provide a good living environment for residents through the surrounding facilities, and the proportion of residential land is suitable. The residential land of Tongzhou Beiyuan is too large, becoming a typical "sleeping city", the surrounding facilities are not perfect, and the fairness can not be guaranteed. The residential land in Beijing West Railway Station, Fengtai Science Park and other stations is too small to meet the housing demand, so the equity index is also relatively low.

## 5. Calculation Results of TOD Development Effectiveness Index of Orbital Station Area in Beijing

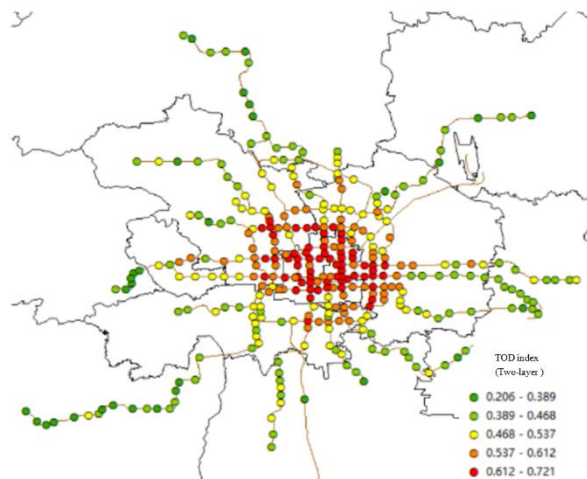
A two-layer evaluation model was used to evaluate the TOD effect of 328 railway stations in Beijing. The upper evaluation results are shown in Figure 8. It can be seen that according to the population travel and activity indicators to evaluate the TOD development effect of Beijing orbital station area, the stations with the best performance are located in two station areas mainly with commercial functions -- Zhongguancun and CBD. Zhongguancun, Bagou, Suzhou Street near a number of institutions of higher learning, research institutes and many high-tech industrial parks, is a more traditional and mature business office, education base; It is close to the Haidian Park, and the green land and the park land can provide people with leisure and entertainment places. There are large shopping malls and supermarkets in this area, and traditional commercial shops such as teahouses and banks are located near Suzhou Street. In addition, there are leisure places such as electronic city and book city. Diversified places provide opportunities for people's activities. Similarly, CBD, Dongzhimen, Dongdan and other station areas are relatively prosperous station areas in Beijing. This area is a gathering place for high-density population activities, integrating office, leisure, entertainment, catering, living and other multi-functions, with a high degree of land diversification and intensification.

The evaluation results of the lower level are shown in Figure 9. It can be seen from the comparison that the TOD development index of Beijing railway station has a significant change when the social equity factor is added. The TOD development effectiveness index of some residential sites in West Second Ring Road increased after the inclusion of equity index. Considering the TOD development effect of the surrounding areas of Beijing railway stations, the stations with good evaluation results are mainly clustered within the second Ring line and the third Ring line in the city center, which are the stations with more prominent TOD development in Beijing. Guomao, Dongdan, Dongzhimen, Xidan and Xizhimen are all transfer hubs with large passenger flow to and from and transfer. Rail

stations should not only lead the supply of large-capacity public transport, but also improve the main functional areas and public transport network within the station area and improve the service level.



**Fig 8.** Results of the Upper -layer evaluation model



**Fig 9.** Results of the Lower -layer evaluation model

## 6. Conclusion

There are many researches on the evaluation of TOD development effectiveness. Scholars mainly selected land use mixed entropy, building density, plot ratio and other TOD planning and design factors for evaluation. Therefore, the pertinence and timeliness of the evaluation results are insufficient, and the support for the tracking evaluation and feedback optimization of TOD benefits is insufficient. Therefore, with the help of big data, machine learning and other methods, this paper proposes a set of dynamic and effective methods for rail station TOD development in Beijing from the perspectives of rail station vitality, travel mode structure, transportation service, social equity, etc., in order to provide scientific basis for the continuous promotion of the TOD model.

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## References

- [1] Calthorpe P. The next American metropolis: Ecology, community, and the American dream[M]. New York: Princeton architectural press, 1993.
- [2] Bertolini L. 1999. Spatial development patterns and public transport: the application of an analytical model in the Netherlands. *Plan. Pract. Res.* 14 (2), 199–210.
- [3] Yang Liya, Shao Chunfu, Nie Wei, Zhao Yi. Evaluation on Relationship Between Urban Transportation and Land Use Based on TOD[J].*JOURNAL OF BEIJING JIAOTONG UNIVERSITY*, 2007(03):6-9.
- [4] Hamid Motieyan, Mohammad Saadi Mesgari. A novel spatial index using spatial analyses and hierarchical fuzzy expert system for obtaining green TOD: a case study in Tehran city[J]. *Geocarto International*, 2019, 34(1).
- [5] Information on [https://www.miit.gov.cn/gxsj/tjfx/txy/art/2020/art\\_6da847bd8676400eaf8074210a6056660.html](https://www.miit.gov.cn/gxsj/tjfx/txy/art/2020/art_6da847bd8676400eaf8074210a6056660.html).
- [6] Information on [https://www.beijing.gov.cn/gongkai/guihua/wngh/cqgh/201907/t20190701\\_100008.html](https://www.beijing.gov.cn/gongkai/guihua/wngh/cqgh/201907/t20190701_100008.html).
- [7] China Sustainable Transportation Center. Chinese city high -quality development TOD index report (2020 version) [R]. Beijing, 2020.