A CONTEXTUAL TRANSIT-ORIENTED DEVELOPMENT TYPOLOGY OF BEIJING METRO STATION AREAS

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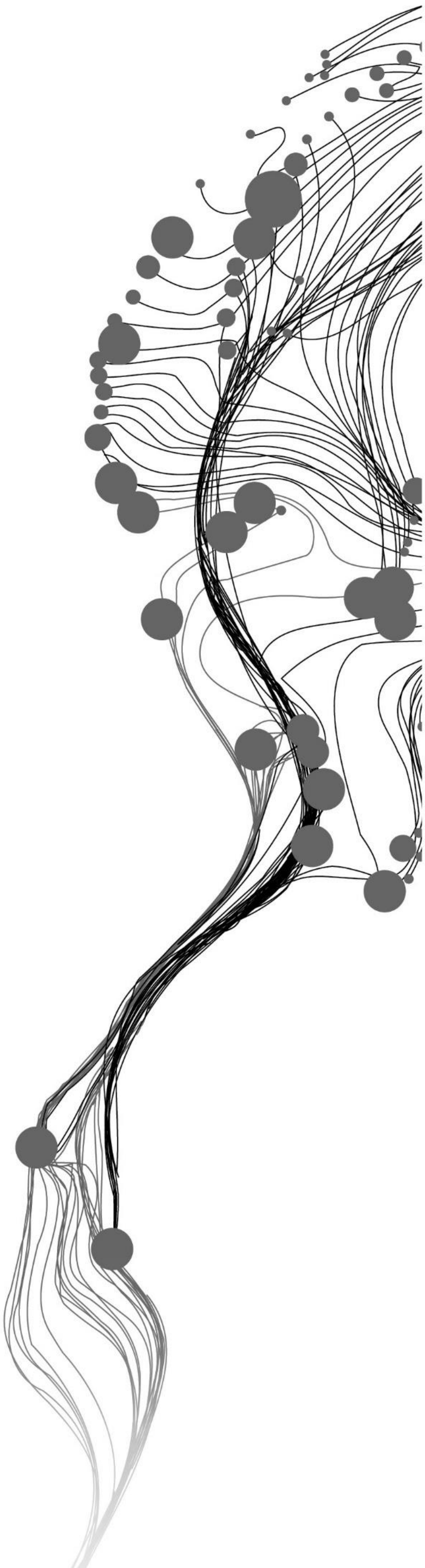

A CONTEXTUAL TRANSIT-ORIEND DEVELOPMENT TYPOLOGY OF BEIJING METRO STATION AREAS

YU LI
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Thesis submitted to the Faculty of Geo-Information Science and Earth Observation of the University of Twente in partial fulfilment of the requirements for the degree of Master of Science in Geo-information Science and Earth Observation.
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ABSTRACT

With the development of urbanization, more and more people live in cities and enjoy a convenient and comfortable life. But at the same time, it caused many issues such as informal settlement, air pollution and traffic congestions, which are both affecting residents and stressing the environment. To achieve intensive and diverse social activities, the demand for transportation also increased, the proportion of cars travelling is getting higher and higher. However, the trend of relying too much on private cars has caused traffic congestion, lack of parking spaces and other issues, which is against the goal of sustainable development.

Transit-oriented development (TOD) aims to integrate the development of land use and transportation, which has been seen as a strategy to address some issues caused by urbanization. It aims to create an environment friendly to pedestrians and cyclists, and encourage a high-mix land use around the transit stations. To measure the existing TOD around the stations, analysis on TOD typology has been aroused great interest rather than ranking a simple TOD index. It groups the station areas with the same characteristics, which helps to know the real situation around the stations and inform the policymaking.

Beijing, the capital city of China, has also increased on population and such these issues. As the important corridors of commuting in people's daily life, the metro network is being planned and constructed with an emphasis in Beijing. Because of the disintegration of urban development and metro system construction, it is important to find out how the TOD concept applies in Beijing and how to measure the existing TOD.

At present, limited factors (e.g., passenger flow, the main land use, or whether the station is a transfer station) were considered in the analysis on the classification of the station areas in Beijing. Due to lack of a relevant guidance document, and several studies have been conducted on TOD typology analysis, this research aims to develop a TOD typology suited for Beijing metro station areas, 26 station areas along metro Line 6 were measured in 2015 and 2020. Based on the planning objectives on TOD and other related planning aspects to find out what is TOD in the context of Beijing. Then, by holding the semi-structured expert interview and going around the metro stations to have a better understanding on the policies and the existing situation in Beijing, and also helped to formulate a set of indicators to describe the characteristics of metro station areas. After that, a node-place model was used to identify the TOD typology. Besides, a sunburst chart was used to visualize the results, which is better to compare the different station areas on each indicator and dimension. Lastly, in order to have an insight into how these station areas changed over time, the data set in 2015 was also applied to the model. The results show the 5 classes of the metro station areas, which are stress, balance, dependence, unsustained node and unsustained place. The change analysis shows although most of the station areas are developing towards balance, there are several station areas with a deviating development. This method effectively measures the current TOD of metro station areas in Beijing. The changes reflect the implementation of the policy to a certain extent and can provide information for future policymaking.

Keywords: TOD, transit-oriented development, TOD typology, metro station area, sunburst chart

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Yu Li

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1. INTRODUCTION

1.1. Background and justification

55% of the world's population lives in urban areas, a proportion that is expected to increase to 68% by 2050 (United Nations, 2018). During the process of urbanization, people's living standards have gradually improved, but at the same time, challenges in the dimensions of demographic, spatial, social, environmental and economic development have emerged, which results in the informal settlement, air pollution, poverty and reducing biodiversity (Black & Henderson, 1999). If mishandled, the growth of cities poses problems that can derail rapid and sustained growth (Spence, Clarke Annez, & Buckley, 2008). Consequently, sustainable development plays an essential role in the successful management of urban growth to achieve a better and more sustainable future for all (United Nations, 2019a). As the world continues to urbanize and motorize, the demand for transportation is expanding (Rodrigue, Comtois, & Slack, 2013). What's more, people are increasingly dependent on private cars to travel longer and participate in social activities (Zhu, Li, Liu, Chen, & Zeng, 2017). This trend has brought out many problems related to economic, social and environmental dimensions, such as increased parking and fuel expenditures, more traffic congestion and accidents, increased emissions from vehicle exhaust, resulting in environmental pollution and harm to people's health (Litman & Laube, 2002). How to solve the traffic problems to meet the increasing demand for transportation is important to achieve the sustainable development goal of providing an affordable and accessible transport system, improving road safety and reducing the adverse environmental impact (United Nations, 2019b).

Transit-oriented development (TOD) is one of the unified and long-term approaches to planning policy that addresses issues such as open space preservation, affordable housing, highway congestion, air quality and infrastructure costs, it has been defined as "a mixed-use community that encourages people to live near transit services and to decrease their dependence on driving" (Calthorpe & Poticha, 1993). A TOD is typically conceptualized as a central transit stop (e.g., a train station, rail station, or bus stop) surrounded by a high-density mixed-use area (Bertolini, 1999). Although the definitions of the concepts of TOD are varying to fit the different contexts, the main idea of TOD is to build a pleasant walking and cycling environment around the station, and develop a high density of building for commercial, residential and entertainment activities, to maximize the land utility, and to promote the living condition of residents and achieve sustainable development (Calthorpe & Poticha, 1993; Cervero, 1998; Dittmar & Ohland, 2004; Thomas et al., 2018; Tumlin & Millard-Ball, 2003).

Assessing the existing situation around stations is vital before implementing a TOD project. Calculating an aggregated score of the TOD level is often used for measurement, each score of level indicates the degree of performance in a particular indicator or index (e.g., the residents within the station area, number of jobs within the station area, area of different land use). Based on the TOD principle, many researchers proposed different frameworks and indicators to measure or evaluate the TOD level, aiming to describe the features around the station in an aggregated value (Alarcón, Cho, Degerstrom, Hartle, & Sherlock, 2018).

However, recent research shows that measuring the TOD level cannot wholly represent the real situation of the area (Huang, Grigolon, Madureira, & Brussel, 2018). The fact that two stations have the same score does not mean they are in the same situation. On the contrary, they may show significant differences in various aspects. Because some specific features cannot be shown with a general value, it is insufficient to use the same criteria to evaluate all the stations and their surrounding areas which are affected by different factors (Calthorpe & Poticha, 1993). Reconnecting America and the Centre for Transit-Oriented

Development pointed out that there are 3 main reasons why differences in different TOD neighbourhoods can occur (CTOD, 2008). First is the difference between the construction conditions of the TOD neighbourhood itself, including land use and traffic. Second is the difference in development orientations and construction standards. The third is the inconsistent role of entities involved in development and construction, such as government, community residents and operating companies.

TOD typology has been seen as a tool for helping plan and manage a large number of sites to identify the homogeneity of the station areas (Kamruzzaman, Baker, Washington, & Turrell, 2014). Several frameworks have been proposed to classify the station areas. Firstly, some researchers focus mainly on the station itself. Calthorpe proposed two scales of TOD area based on their location: urban and neighbourhood (Calthorpe & Poticha, 1993). The urban scale of TOD is located on the mainline of the public transportation network and it is a large transportation hub and the centre of commercial activities within the region. Also, it has a high development intensity and more comprehensive functions. On the other hand, the neighbourhood scale of TOD is mainly located on secondary roads, serving the surrounding areas. This method clearly shows the characteristics of traffic and the station-area but neglects the spatial characteristics of the surrounding areas, such as the location in the commercial centre or suburban residential area. Secondly, the latest classification methods focus on the context and structure of the station area. Belzer and Autler (2002) argue that developing a general typology of places is important to account for a variety of different scales, locations in the metropolitan area, transit type and other vital attributes. Kamruzzaman (2014) also emphasized the importance of built environments factors (for example, infrastructure and services level, mode share, social diversity and inclusion, community engagement). Lyu, Bertolini, and Pfeffer (2016) summarized the indicators from Transit (indicators are the number of directions served by metro, daily frequency of metro services, number of stations within 20 min of travel by metro), Oriented (indicators are the number of residents and jobs, degree of functional mix), and Development dimensions (indicators include the average block size), then these final formulated indicators for classification have been seen as the most significant factors so that the characteristics of station areas can be well described. The second way of classification seems more reasonable for identifying TOD typologies compared with the previous one. Because it not only pays attention to the traffic characteristics of rail transit stations but also concentrates on the intensity and diversity of activities within the station area. This way of classification provides an accurate guide and is conducive to strengthening the pertinence of planning and management in station areas (Kamruzzaman et al., 2014).

Due to market economy reforms and opening-up of the economy and culture, China has experienced a large-scale and rapid urbanization process during the past 40 years (Liang, 2018). Different from the low-density urban development of cities in the developed countries, Chinese cities have long been implementing a relatively high-density development strategy because of the large population and limited resources. High-density development creates the basic conditions for successful implementation of public transport and has prompted China to develop an urban rail transit system (Li, Shi, & Fu, 2015)(Li et al., 2015). TOD provides a new perspective on the adjustment of urban pattern and land use. Aside from the severe congestion, air pollution and high energy consumption caused by motorization, the fragmented management in different sectors for transit, road, and land use planning is also a challenge for implementing a TOD project (Peng, 2012). Although the frameworks and aims proposed in other countries may not be suitable for China, a TOD strategy is still a necessary method to solve urban problems by combining urban development and transportation construction. There is a need to formulate a TOD strategy that suits the Chinese context, rather than applying the successful experiences of developed cities directly to Chinese cities.

The Ministry of Housing and Urban-Rural Development of the People's Republic of China (MOHURD) published the guidelines for planning and design of areas along the urban rail. According to the guidelines, the stations are classified into six types, hub station, central station, transfer station, special control station, terminal station and other station. Each type has different characteristics (see table 1.1) and is formulated corresponding to construction requirements. However, the local guidance document does not discuss how to match these types, only several cities published the TOD guidelines for different station areas, such as Xi'an, Shenzhen and Pearl River Delta Region. The guidelines of these cities classified the station areas by location and functionalities of the surrounding area (Duan & Zhang, 2013; Hou & Li, 2011). While some other guidelines only focus on location characteristics (Liu, 2019).

Table 1 Station type and their characteristics in Guidelines

No.	Station Type	Description
1	Hub station	An important node for transportation interchange of inner-city and the outside, relying on large transportation facilities such as high-speed rail stations.
2	Central station	A station that performs the functions of the city centre or sub-centre. In principle, it is an interchange station for multiple rail transit lines.
3	Transfer station	An important transfer node for the rail transit system and ground public transport system.
4	Special control station	A station located in a special area such as a historical block, a scenic spot or an ecologically sensitive area, which should be controlled by a special requirement.
5	Terminal station	The starting and ending station of the rail transit lines. It should be combined with the depot according to actual needs.
6	Other station	Stations that do not fall into the above categories.

As the capital city of China, Beijing lacks an explicit description of TOD typology. The central government calls for promoting public transit-oriented development, focusing on traffic corridors and large-capacity bus-and-ride nodes, reducing travel time, improving the interchange facilities and parking management (Beijing Urban Master Plan (2016-2035), 2017). In 2018, the proportion of green commuting in central districts was as high as 72%, among them, walking is the main mode for travel, accounting for 29% (Beijing Transport Institute, 2019). While urban rail transit (metro) rides accounts for 16% and it is the most important mode of public transport travel, millions of people depend on the urban rail transit system to and from home to all activities. This study will focus on the typology of metro station areas in Beijing.

In general, developing a context-based TOD typology plays an important role in providing information to planners, developers, officers and citizens (Lyu et al., 2016; Reusser, Loukopoulos, Stauffacher, & Scholz, 2008; Zemp, Stauffacher, Lang, & Scholz, 2011). It can be seen as a measurement tool to assess existing TOD around the stations (Higgins & Kanaroglou, 2016). Besides, it groups the station areas with the same characteristics together, which helps the designers and planners to make strategies and promote TOD (Reusser et al., 2008). What's more, it helps to find the station areas that have common morphological and functional characteristics and clarifies the operational questions in planning (Kamruzzaman et al., 2014; Lyu et al., 2016). Despite the clarity of literature about the TOD typology, less is written about comprehensive and useful methods to identify the characteristics of stations and their surrounding area. This study is intending to contribute in filling this gap using the context of Beijing.

1.2. Research problem

Identifying the TOD typology for station areas is critical. Unlike evaluating all the station areas using an aggregated value of TOD level, TOD typology is a comprehensive and sufficient way to evaluate the characteristics of the station area (Higgins & Kanaroglou, 2016; Huang et al., 2018; Kamruzzaman et al., 2014; Lyu et al., 2016; Reusser et al., 2008; Zemp et al., 2011).

Current typology criteria that are applied in China do not address simultaneously the characteristics of both the station itself and the surrounding area. In the context of China, many researchers paid more attention to one of these two aspects. Liu (2019) summarized that the most common method is to classify the stations according to their transport characteristics. On the contrary, Cai and Zhang (2017) classified the metro stations into the commercial, business, residential and comprehensive station, only based on the main land use type around the station. Although some studies use indicators of both stations and their surrounding areas, they only focus on a small aspect of characteristics, such as land use (MOHURD, 2015; Zhou, 2018). Therefore, a systematic and comprehensive method to classify metro station areas is lacking in a Chinese context.

1.3. Research objectives and research questions

1.3.1. Research objectives

The objective of this study is to develop a contextualised TOD typology for Beijing metro station areas. To achieve the main objective, the following sub-objectives are formulated:

1. To define the TOD concept in the context of Beijing.
2. To identify existing methods to evaluate TOD.
3. To extract indicators for describing the metro station areas in Beijing.
4. To develop an overview of existing methods for TOD typology.
5. To develop a TOD typology suited to the context of Beijing.

1.3.2. Research questions

Based on the 5 sub-objectives, the research questions are posed to guide the analysis:

Sub-objective 1: To define the TOD concept in the context of Beijing:

1) What are relevant planning objectives for TOD in the context of Beijing?
2) What are the important contextual local station area transport planning aspects?
3) Which of these are relevant for TOD in Beijing?

Sub-objective 2: To identify existing methods to evaluate TOD:

1) What are the methods can be used to evaluate TOD?
2) Do these methods allow for the inclusion of context relevance?

Sub-objective 3: To extract indicators for describing the metro station areas in Beijing:

1) What is the size of a TOD area in the context of Beijing?
2) Which features are important for describing the station and its surrounding area?
3) What are relevant qualitative indicators?
4) What are relevant quantitative indicators?

Sub-objective 4: To develop an overview of existing methods for TOD typology:

1) What are the methods that can be used to identify a TOD typology?
2) Which method is the most suited for identifying a contextualized TOD typology?

Sub-objective 5: To develop a TOD typology suited to the context of Beijing:

1) How many types that can be identified for the metro station area?
2) What are the similarities within each type?
3) What are the differences among each type?

1.4. Anticipated results

1. A TOD concept suited to the context of Beijing.
2. An overview of the existing methods to evaluate TOD around the metro station.
3. A list of indicators for describing the characteristics of the metro station areas in Beijing.

4. An overview of existing methods for TOD typology.
5. A contextualized TOD typology for Beijing metro station areas.

1.5. Thesis structure

The thesis is divided into 6 chapters. Chapter 1 introduces the background and justification of the research, then proposed the research objectives and questions. Chapter 2 general summarizes the related concepts and previous research from abundant literature and illustrates the relative applications and methods. A research flowchart is illustrated in Chapter 3, this chapter focuses on the research design, study area description, data and methodology. The results and related analysis will be presented in chapter 4. Chapter 5 is the conclusions of the research, which summarizes the key findings. Last, in Chapter 6, the limitations of this work and potential recommendation for future work will be discussed.

2. LITERATURE REVIEW

This chapter introduces the theoretical framework about TOD from the related literature. Then identifies the existing methods for TOD measurement. Also, provides an overview of the methods used for analysis on TOD typology.

2.1. Conceptualising TOD

In the past 30 years, scholars have been working on TOD to guide the integrated development of stations and their surrounding areas based on the principle of TOD (Calthorpe & Poticha, 1993; Cervero & Kockelman, 1997; Ewing & Cervero, 2010). Cervero and Kockelman (1997) proposed that a 3D principle, Density, Diversity and Design, as the most critical dimensions of TOD. Later, on the basis of the 3D principle, Destination accessibility and Distance to transit used to describe the built environment were added. These 5D criteria were proposed by Ewing and Cervero (2010):

- Density: the number of residents and/or employees that are located within a unit of area, indicating the potential for trip origins and destinations.
- Diversity: the degree of which different land uses are located within proximity of each other, reducing the need to travel outside the area for common trip purposes.
- Pedestrian oriented design: described by the quality of footpaths and pedestrian environment, the connectivity of the road network.
- Destination accessibility: reflecting the proximity or ease of access to regional trip (attractions) opportunities such as employment, which can be measured by distance or time.
- Distance to transit: measuring the distance from the residences or workplaces to the nearest public transport stop or station.

Many more principles were developed later for empirical studies, such as the 8 principles including developing pedestrian-friendly streets, prioritizing bicycle networks, creating dense street networks, supporting high-quality public transportation, designing multi-functional mixed-use communities, matching density with public transportation capacity, create compact areas for short-distance commuting and increase urban mobility by regulating parking and traffic use (ITDP, 2013). Although some of the criteria are interrelated even overlap (e.g., density and diversity coexist), it emphasises the multi-functional nature of a TOD area, aiming to encourage non-motorized forms of mobility within station areas (Huang et al., 2018).

Indicators are used to measure abovementioned factors within a specific distance of a transit station. This distance is defined as the radius of the catchment, the area within the catchment could be seen as a TOD neighbourhood. In general, different researches use different values for this size. Bertolini and Spit (1998) surveyed the travel behaviour of people in front of a rail transit station. The results showed that most people around the station were willing to walk for 5-15 minutes, so they suggested setting the buffer of 400 – 800m as the radius of the adjacent area. While Cervero and Kockelman (1997) took ¼ mile (about 400m) as a range. Feudo (2014) argued that the TOD neighbourhoods typically feature a transit station and public spaces within a half-mile (about 800m) radius.

2.2. TOD measurement

A substantial amount of research has been done to measure TOD. As Higgins & Kanaroglou (2016) claimed that measuring the existing conditions is important for any potential policy interventions to promote TOD. Singh et al. (2014) also state that sound TOD policy and planning for a region must have a thoughtful analysis on those stations and station areas, the remedial actions should also be identified to improve the existing situation.

In travel demand and the 3Ds: Density, Diversity, and Design, Cervero and Kockelman (1997) selected a set of indicators, representing the 3D´s to pursue a regression analysis to evaluate the influence of the built environment (3D's) on travel behaviour. While the indicators can explain the relationship between land use and transport, they might not be sufficient to evaluate TOD.

A series of spatial indicators is used to visualize and quantify eight transit-oriented development (TOD) areas in Portland and Silicon Valley (Galelo, Ribeiro, & Martinez, 2014). More specifically, this report uses a spatial-temporal analysis to measure *transit usage*, *urban form*, and *socio-demographic change*, prior and subsequent to the incorporation of light rail and transit-oriented development policies in these two regions.

TOD measurement is not only done to evaluate the existing situation but also to forecast the potential future situation or inform the expected design guidelines (Galelo et al, 2014). Singh et al., (2014) classified TOD based on a developed actual TOD index and potential TOD index, the first index assesses existing TOD levels, while the second aims to identify appropriate sites for future TOD through this potential value, using spatial multi-criteria analysis.

Another approach to measure TOD is to identify a TOD typology. Grouping stations can diagnose common problems and design targeted policies for specific types. The city of Denver (2014) identified five basic types of LRT and CRT stations for strategic planning: downtown, urban centre, general urban, urban and suburban, based on the *land-use mix*, *street and block pattern*, *building placement and location*, *building heights,* and *mobility*. Then provided three functional overlays (Figure 1), which are innovation, institution and entertainment, for those particular stations are in a key functional aspect according to the station area context and their associated expectations.

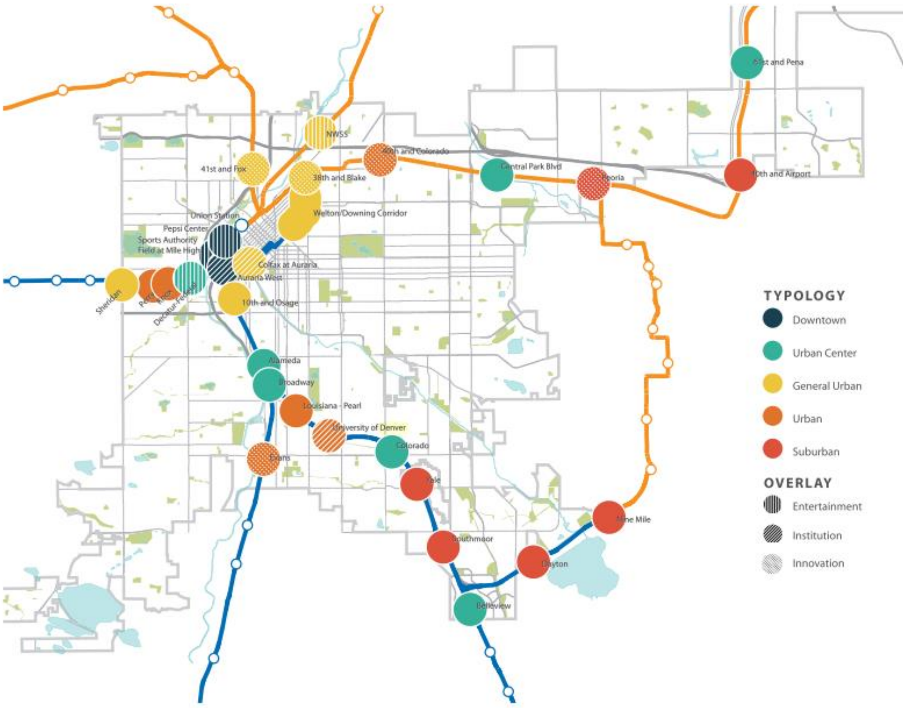


Figure 1 Typology in the Denver city
(Source: Hancock et al. (2014))

Besides, some researchers also committed to analyzing the effects of TOD on travel behaviour, real-estate price, residential location and urban form (Higgins & Kanaroglou, 2016; Kamruzzaman et al., 2014; Park, Ewing, Scheer, & Tian, 2018; Zhao & Li, 2018).

2.3. TOD typology

2.3.1. Normative TOD typology

Developing TOD typologies started in America in the 1990s. Calthorpe and Poticha (1993)recognized that there could be no 'one-size-fits-all' method to TOD, so he first proposed urban and neighbourhood scale TOD implementations. His study is the basis of the TOD typology method. Dittmar and Ohland (2004) argued that the typology should be more sophisticated and proposed six TOD types: urban downtown, urban neighbourhood, suburban centre, suburban neighbourhood, neighbourhood transit zone and commuter town centre. This method is more concerned with the spatial location of the station. These approaches are summarized as normative TOD typologies by Higgins (2016), it outlines the general characteristics of different TOD types in terms of densities, housing types and transit service.

2.3.2. Positive TOD typology

2.3.2.1. Node-place model

The positive method refers to the typology developed based on a positive assessment of existing TOD conditions, it began from the work of (Bertolini, 1999), who classified 17 rail station areas in the Netherlands using a node-place model. The model follows the theory of the land use-transport feedback cycle (Figure 2). Improving the transport provision (accessibility) of a location will stimulate the land use development at that location. In turn, the diversification and intensification of land use in a location will stimulate the further development of infrastructure (Bertolini, 1999; Hanson & Giuliano, 2004; Sanders, 2015; Wegener & Fürst, 1999).

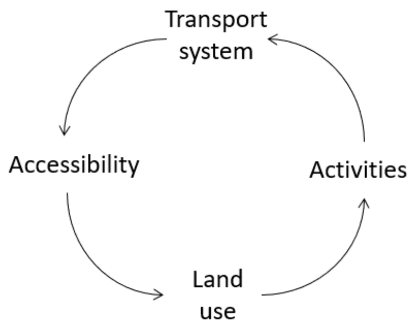


Figure 2 The land use-transport feedback cycle
(Source: Wegener & Fürst, 1999)

In the node-place model, node and place are two axes. The node value refers to the accessibility of the node, measures the intensity and diversity of the transport supply in a station location (Bertolini, 1999; Practice, Peek, Rotterdam, Bertolini, & Jonge, 2006). Airports, ports, rail stations, metro stations and other transportation hubs are often considered as nodes in the transportation network, whereas place refers to the intensity and diversity of the activities that can be reached within the station area (Jacobs, 2000; Sanders, 2015).

The node-place model (Figure 3) indicates that the Y-axis represents the accessibility of node, the higher the node value, the more people arrive in the area, and the higher the frequency of people's activities; The X-axis represents the intensity and diversity of land use around the station, the higher the place value, the higher the diversity of land use functions, and the more types of people's daily activities take place (Bertolini, 1999).

The five ideal-typical situations in the node-place model are stress, balance, dependency, unsustained node and unsustained place. For sites that can be placed in the "balance" area, the transport infrastructure supply and land use patterns have a degree of matching, the value of node and place is equally strong. While the right upper corner is the "stress" area, here both the node and place have the highest value, indicating that the land has been fully utilized and the infrastructure has been fully developed. Conversely, in the "dependence" area, residents have a lower demand for transportation and urban activities, so it can meet the requirements through the intervention of other factors (such as regional morphological characteristics or the shape of the transportation network, external subsidies). For the "unsustained node", the place value can be increased such as attracting new real estate development, or reducing the node value such as reducing transportation supply to achieve the balance; the opposite occurs in "unsustained place".

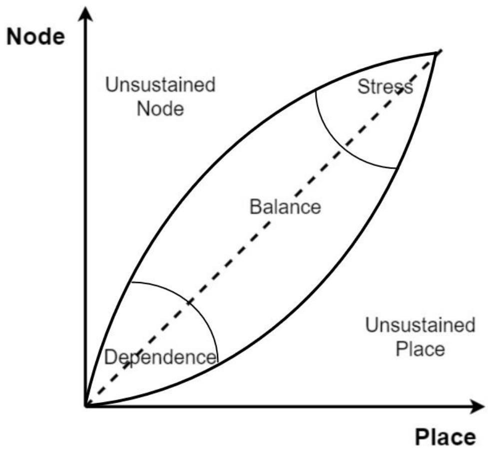


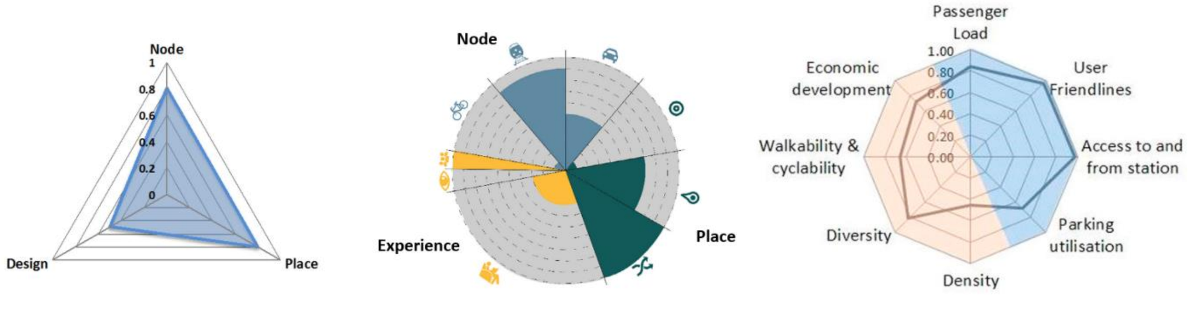
Figure 3 The node-place model
(Source: Bertolini, 1999)

Zemp et al. (2011) expanded Bertolini's work and claimed that the indicator passenger frequency insufficiently describes the stations. They formulated the context factors from five functions of railway stations in Switzerland: link catchment area and transport network, support transfer between modes of transport, facilitate the commercial use of the real estate, provide public space and contribute to the identity of the surrounding area. Maidina and Mu (2018) established a node-place model of 7 metro stations and 7 BRT stations in Urumqi, China, to evaluate the integration of urban transport and land use.

2.3.2.2. Modified node-place assessment models and visualizations

In addition to the original node-place model, some scholars proposed several optimized assessment models by adding criteria to generate station typologies, besides node and place. While innovating the models, scholars are also using appropriate charts or diagrams to visualize the performance of a station on the different criteria and allow comparisons between stations. Generating typologies and visualizing the performance of stations on different aspects for comparison are the dual purposes served by the modified models (Caset, Teixeira, Derudder, Boussauw, & Witlox, 2019).

An extended node-place model was built by Vale et al. (2018) to re-evaluate Lisbon's subway stations, it contains 3 axes, node, place and design (see Figure 4a), the design dimension measured the walkability of the station areas. Similarly, Groenendijk, Rezaei, and Correia (2018) proposed to add a new axis "experience", which represents the traveller's perspective from a survey among 140 respondents. This Node-Place-Experience model was used to assess the perceived quality of transit nodes in Rotterdam city and visualized using a rose diagram (see Figure 4b), all the indicators can be shown in the diagram rather than in an aggregate index. Many scholars have extended the two or three axes to more dimensions. Singh et al. (2017) also measured walkability and bikeability, and expanded the model into 8 dimensions: economic development, walkability and cyclability, diversity, density, parking utilisation, access to and from the station, user-friendliness and passenger load, the results were shown in a web diagram (see Figure 4c). The detailed examples of other adapted models can be seen in Caset (2019).



(a) Extended node-place model (Vale et al., 2018)
(b)Node-place-experience model (Groenendijk et al., 2018)
(c) Web diagram (Singh et al., 2017)

Figure 4 The examples of modified node-place models and their visualizations

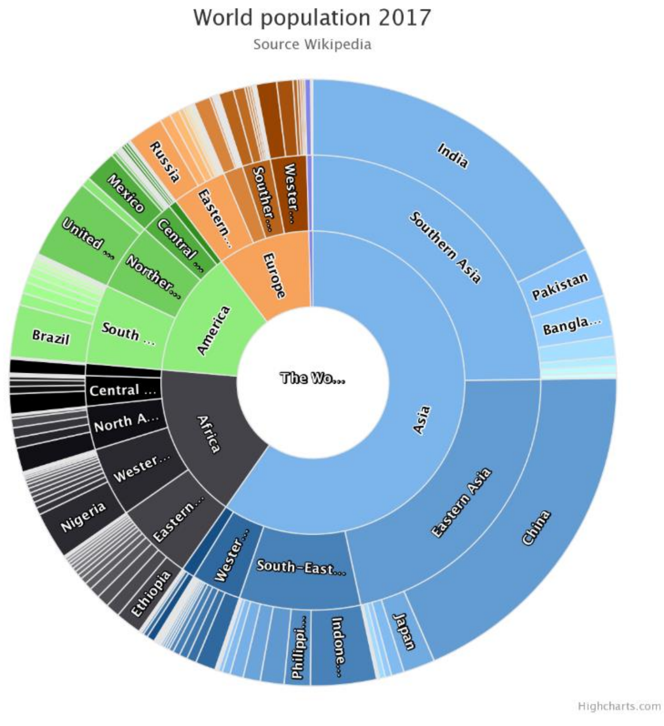


Figure 5 One example of the sunburst chart

(Source: High charts (https://dataforvisualization.com/charts/sunburst-diagram/))

From all the above models and visualizations, some charts (Figure 4a & 4c) only show the index value, the detailed values for each indicator cannot be seen. While the value of indicators can be clearly seen in the rose diagram, however, the index level is not displayed. To visualize an explicit hierarchy of indicators, the sunburst diagram will be used in this study. The sunburst chart provides more information on the hierarchical data, it consists of an inner circle surrounded by rings of deeper hierarchy levels, the angle of each segment is either proportional to a value or divided equally under its parent node, all segments in this chart may be coloured according to which category or hierarchy level they belong to (van Vught & Ziegele, 2012). Figure 5 is one example of a sunburst chart, it shows the population in 2017 of different countries and continents. The first ring shows the population of each continent, the second ring represents the different geographical part of the continent, the third ring stands for each country. The structure of dimensions and indicators can be shown in this way, the value of both indices and indicators can be visualized together.

2.3.3. The methods used for classification

Making an index is one of the methods used for classification. All the indicators are formed to a node and a place index respectively and plotted in a simple x (place) and y (node) diagram (Caset, 2019). The multi-criteria analysis was applied to evaluate 13 train station areas in the Utrecht region and the dynamic change of 20 train station areas in the Amsterdam region between 1997 and 2005 (Bruinsma, Pels, Priemus, Rietveld, & Van Wee, 2008) (Figure 6). Besides, Maidina and Mu (2018) calculated the average values of each indicator to make a node index and place index, 14 stations in Urumqi were classified to 6 types by measuring the node indicators (e.g. percentage of sidewalk area and the distance to the trunk road) and place indicators (e.g. residence population and number of workers in each economic clusters).

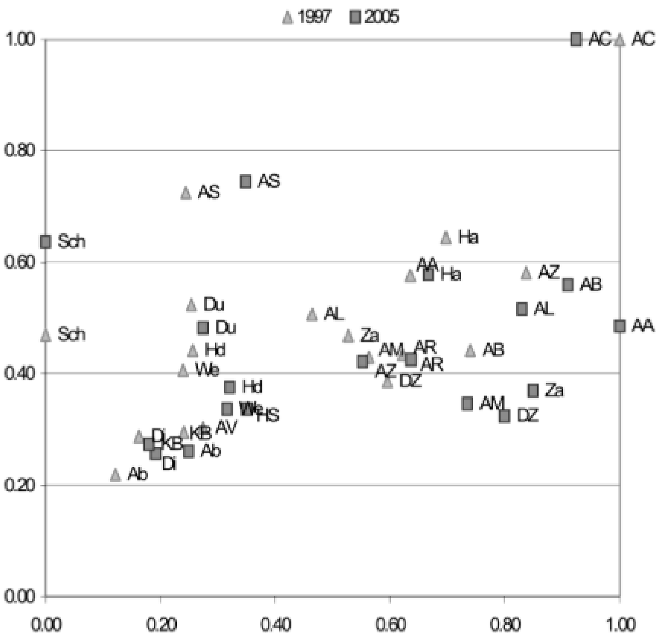


Figure 6 The application of node-place model
(Source: Bruinsma et al., 2008)

Cluster analysis is another method for creating a typology. K-means, hierarchical are the traditional cluster analysis methods, many research has been conducted using these unsupervised cluster methods (Lyu et al., 2016; Xu et al., 2018; Zemp et al., 2011; Zhou, 2018).

However, traditional cluster methods cannot provide a subjective and convincible number of clusters, therefore, a two-step clustering method was applied to the analysis. This method requires that preclusters are formed in the first step, then the number of clusters is determined using the Bayesian Information Criterion (BIC), followed by a standard hierarchical clustering procedure. Reusser et al. (2008) assessed all Swiss railway stations by a two-step clustering and enhanced the node-place model by considering the additional indicators relevant to sustainability judgements (e.g. passenger frequency, distance to the town centre, commercial services), which were extracted from an expert questionnaire and interviews.

Kamruzzaman et al. (2014) identified four unique TOD clusters (residential TODs, activity centre TODs, potential TODs and TOD non-suitability) by using a two-step cluster analysis in the case of Brisbane. Six aspects of the built environmental were quantified and measured: net employment density, net residential density, land use diversity, intersection density, cul-de-sac density, and public transport accessibility.

Recently, the Latent class cluster analysis is a preferred method for generating a TOD typology recently. This method can use BIC or entropy during the procedure to support the decision of the number of classes. Besides, it accommodates the variables without standardization, the output of the model can be interpreted using with original value and unit. Higgins (2016) analyzed the TOD input performance of station areas by using a latent class cluster analysis. Based on the 5D principle, the 372 rapid transit stations were classified into ten distinct types (urban commercial core, urban mixed-use core, inner-urban neighbourhood, urban neighbourhood, outer suburban neighbourhood, suburban centre, outer suburban commerce park, outer suburban commerce park, outer suburban industrial park and airport) according to the input measure factors.

Although the cluster analysis is often used to classify the station areas, it is not suitable for this study. This is mainly because the cluster analysis requires a large number of samples, if it applies to the experimental objects with fewer samples, and the distribution of is scattered, then it may be divided into many categories, and the number of samples in each category is very small, so the classification results have no intention. Conversely, if the number of the class is small, the samples in each category may be very different. Such classification results are unconvincing and hard to interpret. The classic node-place model aims to find out the relationships between node and place of the station areas at different locations in the model. Therefore, the node-place model was applied to this research.

2.4. Summary

Based on reviewing the related literature about TOD, it systematically introduced the concept and development of TOD. Besides, it introduces the existing methods and applications for measuring TOD. Instead of an aggregated TOD level, the TOD typology seems to be better to identify the characteristics of the station areas. Furthermore, it provides an overview of the methods used for classification.

Part of the literature and the measuring dimensions they focusing on are listed in Table 2. In general, it can be concluded that although the selected indicators and methods vary for different study areas, the shared objective is to provide empirical information on identifying different development opportunities for station areas depending on the regional context.

As the importance of applying context, in addition to reading related policies and documents in Beijing, interviewing experts who have local knowledge and background is also an important method of this research. With the working experience and familiarity of the reality of Beijing, the experts helped to formulate the indicators which are important to describe the metro stations. Based on the literature review, a general list of indicators was formed and is shown in Table 3.

Lastly, the node-place model would be used to identify the TOD typology, because it clearly shows the different relationship between the node and place according to the position. Besides, the sunburst chart would be used to visualize the results, as it can completely show the multi-level data and be compared intuitively.

Table 2 Different measure dimensions used for TOD typology

Measuring dimension			Literature source
Accessibility of stations or network	**Intensity and diversity of activities**	**Passengers' experience or satisfaction**	
√			Calthorpe and Poticha (1993; Dittmar and Ohland (2004)
	√		Liu (2019)
√	Part of		Zhou (2018); Hancock et al. (2014)
√	√		Bertolini (1999); Higgins & Kanaroglou, (2016); Kamruzzaman et al. (2014); Lyu et al. (2016); Zemp et al. (2011); Duan and Zhang (2013);
√	√	√	Groenendijk et al. (2018); Olaru et al. (2019)

Table 3 General list of indicator extracted from the literature

Dimension	Indicator	Literature
	Daily frequency of metro services	Caset et al. (2019), Groenendijk et al. (2018), Reusser et al. (2008), Zemp et al. (2011), Vale et al. (2018)
	Number of staff	Reusser et al. (2008)
	Number of connection track lines	Reusser et al. (2008), Zhou (2018)
	Passenger volume	He (2018), Singh et al. (2017)
	Distance to the city centre	Zhao and Li (2018), Zhou (2018)
	Entrances/exits	He (2018)
	Number of metro stations within 45 minutes of travel	Bertolini (1999)
	Number of metro stations within 20 minutes of travel	Lyu et al. (2016), Reusser et al. (2008), Zemp et al. (2011), Zhou (2018), Vale et al. (2018)
Surrounding area	Number of connection methods	Groenendijk et al. (2018), Olaru et al. (2019)
	Number of each connection method	Groenendijk et al. (2018), Maidina and Mu (2018), Olaru et al. (2019), Reusser et al. (2008), Zemp et al. (2011), Zhou (2018)
	Parking lot	Groenendijk et al. (2018), Haershan and Rui (2018), Zhou (2018)
	Sidewalk facilities	Caset et al. (2019), Huang et al. (2018), Singh et al. (2017)
	Bicycle lane facilities	Caset et al. (2019), Huang et al. (2018), Singh et al. (2017)
	Intersection	Huang et al. (2018), Kamruzzaman et al. (2014), Park et al. (2018), Vale et al. (2018)
	Population density	Atkinson-Palombo and Kuby (2011), Huang et al. (2018), Olaru et al. (2019), Singh et al. (2017), Zemp et al. (2011)
	Job density	Atkinson-Palombo and Kuby (2011), Caset et al. (2019), Huang et al. (2018), Olaru et al., (2019), Singh et al. (2017), Zemp et al. (2011)
	Number of POIs	Vale et al. (2018)
	Road density	Zhao and Li (2018)
	The area of green space, square and park.	He (2018)

	Mixed land use	Higgins and Kanaroglou (2016), Huang et al. (2018), Zhou (2018)
	Air quality	He (2018)
	Noise	He (2018)
Passengers' experience	Experience	Groenendijk et al. (2018)
	Satisfaction	He (2018)

3. DATA AND METHODOLOGY

This chapter consists of three sections. The first one introduces the general steps to reach the research objectives, the flowchart of this study is illustrated in this part. The second part introduces the case study, including the study area and the related policies. The third one focuses on the methodology, including how to design interview, how to get and process data, and the method used for identifying TOD typology.

3.1. Research design

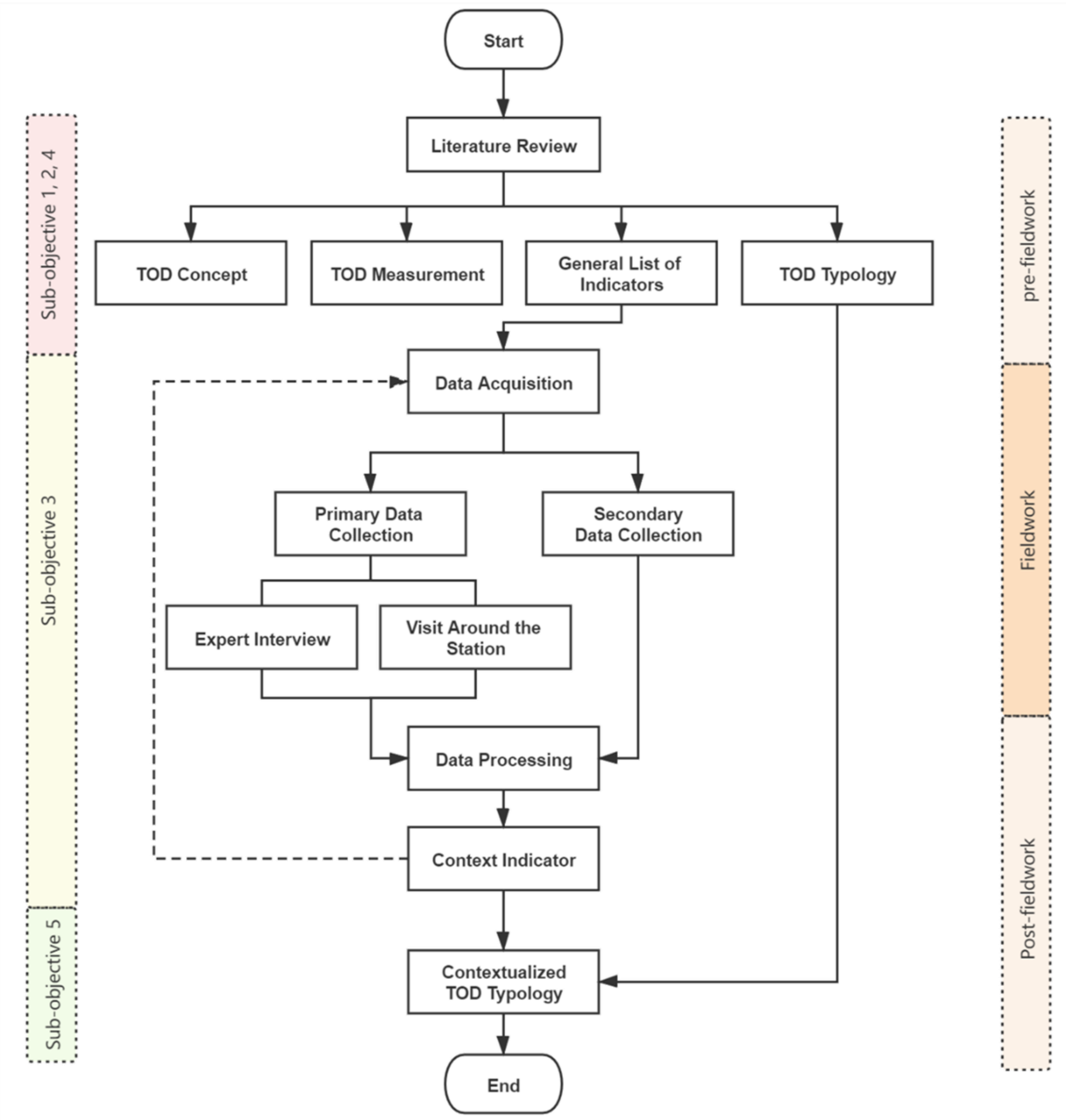


Figure 7 Research design

Figure 7 shows the research design of the thesis. The literature review answers to sub-objective 1, 2, 4, and part of sub-objective 3 and 5. A general list of indicators was formulated from the related literature, 8 experts who are in the fields of transportation and urban planning were interviewed to complement these indicators and provide insights on Beijing TOD planning and development. Field visits were made around the metro stations to obtain primary data. In addition, communicating with staff in the metro station to better understand the metro operation situation and the residents around were asked to express their travel behaviour or willingness, and changes in surrounding land use over time. After that, the required secondary data were downloaded from the websites to calculate the indicators. After collecting all the data, each indicator was calculated, factor analysis was used for dimensionality reduction to form the input data of the TOD typology.

3.2. Case study area description

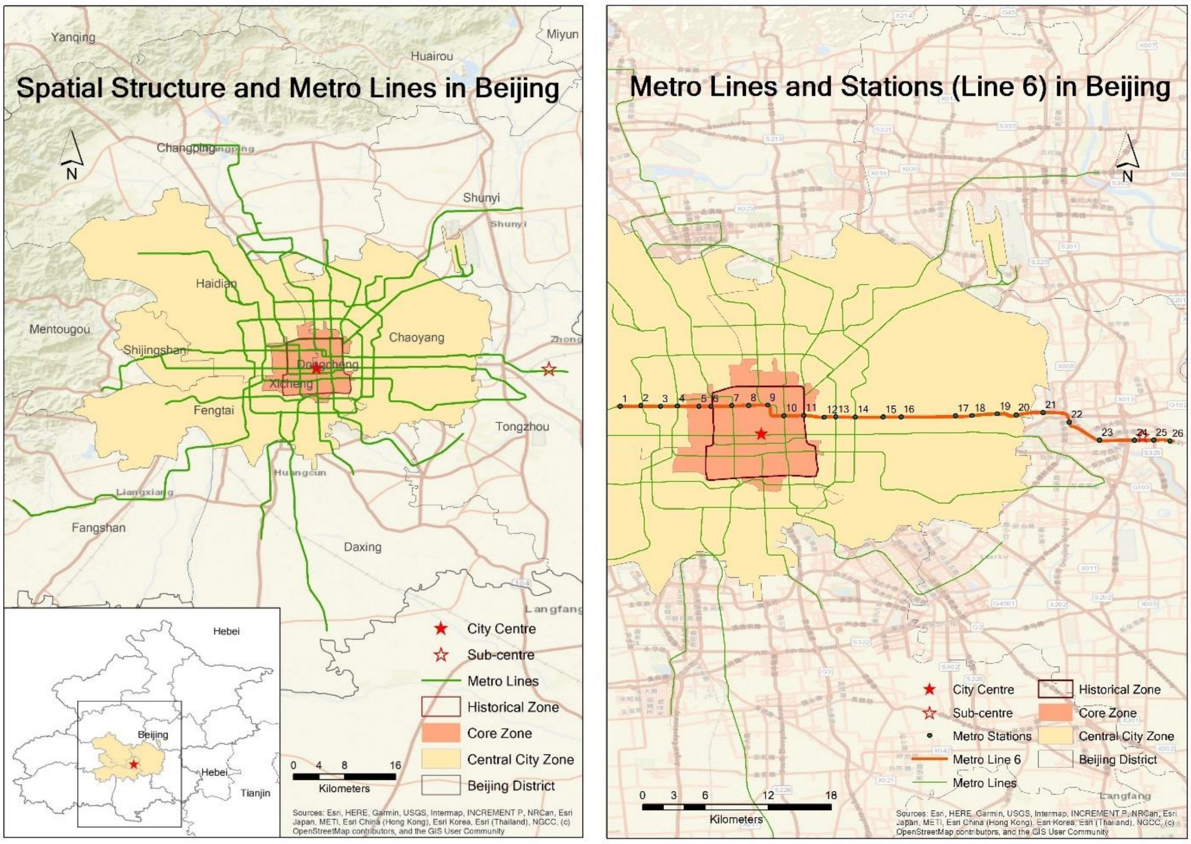
The study area is located in Beijing. As of December 2019, there are 23 operating metro lines in the Beijing urban railway transit system, which has a total length of 699.3km and 405 stations (including 62 interchange stations) (Figure 8). According to the Beijing Urban Master Plan of 2016-2035 (2017), the urban rail transit network will reach more than 1000 kilometres in the year 2020 with 33 operation lines, covering the 16 districts of Beijing and connecting the suburban areas and the city centre.

The master plan clarifies the spatial structure of Beijing (see Figure 8a), which consists of one core zone, one central city zone and one city sub-centre. The core zone is the core area of the capital's functions, which requires to ensure the leading organs of the government and efficiently work of the military, as well as protect the historical zone and inherit the culture and architecture of the ancient city. The central city zone includes 6 districts of Beijing, which are Xicheng, Dongcheng, Chaoyang, Haidian, Fengtai and Shijingshan. The main task in this zone is to phase out non-capital functions and ease the "urban diseases". Non-capital functions refer to manufacturing, logistics and wholesale markets, they will be relocated to the new town outside Beijing.

The Beijing city sub-centre, as a planning and construction area in the new town, requires the functions that connect with the central city zone and relocate population, taking administrative offices, business services, and cultural tourism as the priority functions to form an area with complete and comprehensive functions. Beijing sub-centre was proposed by the municipality in 2012. The construction of the Beijing city sub-centre is to adjust the spatial pattern of Beijing, manage the "urban diseases" and expand the development of new spaces, as well as to promote the coordinated development of Beijing, Tianjin and Hebei, and to explore the optimization of development in densely populated areas.

As a transportation hub connecting the central city zone and sub-centre of Beijing, metro line 6 is selected as the study area (Figure 8b). Metro line 6 is the 15th line opened in Beijing. It serves as the second trunk line that runs east-west across Beijing, goes through 6 administrative districts and important functional zones including the historical zone and the core zone, the central city zone and the sub-centre of Beijing city. The first phase of the project opened on December 30, 2012, from station Haidianwuluju (1) to Caofang (20) (station ID see Figure 8b). The second phase of the project, from station Caofang (20) to Lucheng (26), opened on December 30, 2014, Beiyunhedong station in this phase delayed to open in 2018. The west extension part, from station Haidianwuluju (1) to Jinanqiao, opened on December 30, 2018.

The planning period of the Beijing master plan is from 2016 to 2035, it clearly defined the basic framework for urban development by 2035 and the short-term goal by 2020. This study will offer a method to classify the metro station areas and apply it to all the stations that have been operating in 2015 along the metro line 6. The study will focus on the changes of stations along line 6 after the implementation of the new master plan, so the changes from 2015 to 2020.



(a) Spatial structure and metro lines in Beijing (b) Metro line 6 and stations

Figure 8 Study area

(Source data: OpenStreetMap and Geospatial Data Cloud.)

3.3. Methodology

3.3.1. Fieldwork

The expert interview is one of the methods to fulfil the research objectives. To get professional and authoritative insights on the status and development of Beijing's transportation and land use, several experts were invited to answer the related questions and express their opinion based on their work and life experience. By contacting them via email in advance, 7 experts were finally interviewed face-to-face, including scholars with relevant research backgrounds, government officials with more than 10 years of work experience in urban planning and transportation system management, other stakeholders related to land use, such as retail staff and real estate developers. The information of the experts is shown in Table 4.

Before starting the expert interview, an interview document (see Appendix 1) was prepared, which includes the brief introduction of the research topic, the aim of the interview, the questions, and the indicator list. The documents with explanation were distributed to experts via email in advance to ensure they understood the thesis topic and technical terms. For the indicator list, which was summarized from the extensive literature review. In addition to answering the questions, the experts were also asked to rank dimensions and the indicators of each dimension in the order of importance and add or modify the indicators they considered important. They were also welcomed to make more suggestions on the thesis operationalisation. All notes were recorded on the printed documents with the consent of the interviewee and were transcribed after interviews. Although the face-to-face interviews have ended, the experts were asked to perform new sorting on the additional indicators proposed from others via email.

Table 4 Experts' information

No.	Company	Occupation/Position	Background	Working-age
1	The People's Government of Beijing Municipality	Confidential	Urban planning	15
2	Beijing University of Technology	Associate professor	Planning and design of walking and cycling systems, public transportation systems.	12
3	Decathlon Group Co., LTD	Salesman	Retail	7
4	China State Construction Engineering Corporation (CSCEC)	Real estate developers	Real estate developers	18
5	China Agricultural University	Lecturer and Researcher	Urban planning	-
6	Beijing UN-Construction Group Co., LTD	Constructor	Construction	15
7	The People's Government of Beijing Municipality	Confidential	Planning and management of public transportation systems.	11

Apart from the experts' interviews, the staff at the metro stations and the residents around the stations also helped to understand the detailed real-life situation. The staff introduced the operation situation, such as whether to increase the frequency during the rush hours. Moreover, to have a better understanding of the travel behaviour around the stations, residents who are familiar with the station areas were randomly picked to introduce their daily travel routes, feelings, and suggestions on how to improve the satisfaction of the travel experience.

In addition, through going around the station to collect the primary data which cannot be obtained from the digital map, such as the effective width of the walking side and the cycle lane, to see whether they were occupied by parked bicycles or motor vehicles. Simultaneously, the POI data captured from the website was verified in the field to ensure the accuracy of the available data.

3.3.2. Context indicator formulation and operationalization

According to the official guidelines for planning and design of areas along urban rail lines (Ministry of Housing and Urban-Rural Development of the People's Republic of China (MOHURD), 2015), a radius of 300-500m around the rail transit station is called the core area of the station, and the area of 500-800m around the station is called the influence zone. The overall objectives for the station planning are 1) to implement the principles of ecological restoration and mending the metropolis, taking the stations as the core to build a human-oriented, environmental-friendly, sustainable operation and management urban space; 2) to integrate the entrances/exits and surrounding buildings, public space, to shape an environment of all-weather and barrier-free transportation hubs; 3) to promote the integrated use of underground and above-ground space in the core area of the stations, rationally plan the functions of surrounding properties, and promote the combination of transportation functions and urban living service functions. Following the official guidelines, a radius of 700 meters of the metro station was seen as the catchment size of a TOD, because the distance between two stations is about 1500 m.

The combined results of experts' opinion and the available data, the selected indicators and their scores are shown in Table 5. The experts were asked to rate each indicator and dimension separately from 0 to 10, according to the importance they think. The most important indicator was given 10 points, then the second one is given 9 points, and the unimportant indicator was 0. Add up the total score of each indicator or dimension and calculate the proportion to get the weight of them.

Table 5 Dimensions and indicators

Dimension	Sub-dimension	Score	Indicator	Score
Node	Accessibility	1	N1 Proximity to the city centre.	0.14
			N2 Number of entrances/exits.	0.15
			N3 Number of metro stations can be reached within 20 minutes of travel by metro	0.22
			N4 Distance to the nearest shop.	0.12
			N5 The number of served directions by the metro.	0.13
			N6 Passenger volume.	0.24
Place	Bus connection	0.24	C1 Number of connected bus stops.	0.36
			C2 Number of served bus lines.	0.22
			C3 Distance to the nearest bus stop.	0.42
	Facilities	0.24	F1 Number of the parking lot.	0.28
			F2 Effective width of the cycle lane.	0.20
			F3 Effective width of the sidewalk.	0.20
			F4 Number of signalized intersections.	0.22
	Density	0.30	D1 Population density.	0.34
			D2 Job density.	0.35
			D3 Road density.	0.31
	Diversity	0.22	S1 Commercial stores.	0.25
			S2 Public services.	0.25
			S3 Government agencies.	0.25
			S4 Land use mixed.	0.25

3.3.2.1. Measuring the node index

The indicators in the station dimension describe the traffic characteristics of the metro stations. Especially the location and the physical properties of the stations.

N1 Proximity to the city centre

Although some respondents believe that distance from the city centre is not the determining factor for commuting, the location of the station is indeed an important physical factor. This indicator was done by calculating the Euclidean distance between the city centre and stations. The city centre is located in Tian'an Men square.

N2 Number of entrances or exits

Unlike the metro stations designed in Paris, Tokyo or other cities in Southern China, metro stations in Beijing generally have 4 exits. The entrances and exits should achieve an integrated connection with surrounding roads, buildings and public regions. If there is a large shopping mall or several office buildings near around the station, then the number of exits will increase and they may connect directly connect the underground space. Besides, the interchange station of multiple lines will have more exits. The more exits, the more directions people can access to the station. The exit information can be obtained from the Beijing subway official website (https://www.bjsubway.com/station/xltcx/).

N3 Number of stations within 20 min of travel by metro

The accessibility of the metro station was calculated by counting the number of metro stations that can be reached within 20 minutes, including the stations reached from the interchange station. Bertolini (1999) calculated the stations that can be reached within 45 minutes, Reusser et al. (2008) used 20 minutes to better adjust to the Swiss constraints and to reduce computational effort. When calculating how many stations can be reached within 20 minutes, the total travel time including the waiting time, travel time on the metro and transfer time. The departure interval of Line 6 is about 6 minutes, so the average waiting time is 3 minutes. The time table for each metro line can be found on the Beijing subway official website (https://www.bjsubway.com/e/action/ListInfo). The transfer time is the walking time for transfer distance.

N4 Distance to the nearest shop

The distance from the entrances/exits to the nearest shop shows the attractiveness of the metro station to a certain extent. Sometimes facing an entrance or exit of the metro station is a wall or the road, like Figure 9a shows, passengers would feel lost. Conversely, if there are many convenience stores around the entrances or exits, the station would look more attractive, like Figure 9b.

(a) Exit C (b) Exit D

Figure 9 Different exits of the Shilipu station
(Source: Baidu panoramic image (http://map.baidu.com/))

This indicator was done by measuring the walking distance between the exit and the nearest shop or convenience store. The location information of the stores and exits is the point of interest (POI) data captured from Gaode Map (https://www.amap.com/), using the Ranging Tool in Gaode Map to measure the distance.

N5 The number of served directions by the metro

The terminal stations only have one direction, the interchange station of multiple lines will have three or more directions. This information can be found in the Beijing subway official website (https://www.bjsubway.com/station/xltcx/).

N6 Passenger volume

Due to lack of sufficient data, only data from July 2018 was available, so this indicator was deleted. the passenger volume is used for analysis in the next stage. The data comes from smart card swiping record collected by Beijing metro operation department, including the card number, card type, inbound station, time and outbound station, time, and some other information of the cardholder.

3.3.2.2. Measuring the place index

The indicators of the surrounding area dimension describe the characteristics within a catchment area of the metro stations.

(1) Bus connection

The “Guidelines” states that the priority selection of interchange should be walking, cycling, ground bus, taxi and car. In addition to the requirements for walking and cycling environments, bus systems, as the second most popular mode of public transportation in Beijing, are also very important, which was also the consensus of experts. To reduce the mutual impact of motor vehicle traffic and control the total transfer time, transfer transportation facilities should be arranged suitability.

C1 Number of connected bus stops

The number of connected bus stop within the TOD neighbourhood can be counted, and also the served bus lines. The bus stop data was the POI data captured from Gaode Map.

C2 Number of served bus lines

The bus line information is one of the attributes of each point item.

C3 Distance from the exit to the nearest store

The walking distance between the bus stop and the exits of rail transit stations should be controlled around 50-100m. So the indicator is the walking distance from the exit to the nearest bus stop. This distance was measured by the Ranging Tool in Gaode Map.

(2) Facilities

F1 Number of the parking lot

Sufficient parking lots can attract more visitors and increase the social vitality of the surrounding area. The parking lot and bicycle parking should be provided near the station. On the contrary, the lack of parking facilities may reduce customer visits. Beijing Metropolitan pedestrian shopping street had not attracted many visitors because it has no planned bicycle lanes and parking lots. In order to increase the number of visitors, it has converted a square into a parking lot to facilitate tourists who drive. Therefore, the number of parking lots was calculated, using POI data to count the number of parking within the station area.

F2 Effective width of the cycle lane, F3 Effective width of the sidewalk

The connected pedestrian system should be as convenient as possible to avoid detours. Comprehensive consideration of shading and rainproof facilities, decoration, paving, signs, etc., to ensure the environmental quality of the walking space. The effective widths of the sidewalk and cycle lane were considered more important than the length in the Beijing context because the primary and secondary roads and branch roads in the core area are equipped with complete sidewalks and cycle lanes. But they are often occupied as is shown in Figure 10, private cars have increasingly parked on the road with a bicycle sign.

(a) 2013 (b) 2017

Figure 10 The sidewalk and cycle lane near the Huayuan Qiao station in different year
(Source: Baidu panoramic image (http://map.baidu.com/))

Being convenient and environmentally friendly, shared bikes suddenly came out in 2016 and have already been popular throughout China. However, with its favoured by many people, it brings out many problems. In some places, there were no fixed bicycle parking spots, the shared bikes are left everywhere and the sidewalks are occupied by them.

These are two important indicators to describe the station area. According to the document (Beijing Municipal Commission of Planning and Nature Resources, 2014), it requires the sidewalk and cycle lane to be 2m and 2.5m in width, respectively. To calculate the indicator, the effective width was divided into three levels, 1 - less than the standard, 2 - approximately equal to the standard, 3 - larger than the standard. If there is no separate cycle lane or sidewalk, the value is 0. The available data was captured from the panoramic image (http://map.baidu.com/), and there are images of different years, from 2013 to 2018. The indicators would be judged from the panoramic image. The street index calculated by the CityDNA team was also used for reference, which was focusing on the quality of sidewalk and cycle lane, including the index like the width of the road, whether there is a green shade, a guardrail, whether it is safe and convenient (http://demo.citydnatech.com/streetmapping/).

Although the cycle lanes and motorways should be physically separated in the influence zone, it is also worth noting that one expert claimed that some of the guardrails have been removed in the past two years in Beijing because they were not considered as good protection facilities, which can be seen in Figure 11.

(a) 2013 (b) 2017

Figure 11 Removing the guardrails

(Source: Baidu panoramic image (http://map.baidu.com/))

The number of intersections with signal lights was counted within the study area using POI data. The intersection reveals the connectivity of the road network.

(3) Density

D1 Population density

For the sub-dimension density, the population density was measured by the real-time population data obtained from the Baidu location-based service big data platform (https://map.baidu.com). It is based on mobile phone signals to capture the real-time location of users, which can reflect the spatial distribution of the population. The original data is stored in CSV format and contains 4 fields: count, longitude, latitude and acquisition time. The population point data was captured at 10 pm on 6th April, with an accuracy of 25m. The indicator was calculated through the total population and the area of each TOD neighbourhood.

The residential population density in 2015 was calculated by the population in neighbourhood overlapping by the station areas, the data was obtained from the Beijing census data in 2010 (http://tjj.beijing.gov.cn/tjsj/yjdsj/rk/2020/index.html).

D2 Road density

The road density was calculated by the total road length and the area of TOD neighbourhood. The road data was captured from OpenStreet Map (http://download.geofabrik.de/asia/china.html).

(4) Diversity

As data are not available, the workforce was characterized by the number of economic entities. There are three economic clusters, S1 commercial stores (retail, hotel, catering and entertainment), S2 public services (education, culture and medical) and S3 the government agencies. All of these data were the POI data obtained from Gaode Map (http://amap.com/).

The Guidelines encourage a reasonable mix of functions in the core area of the rail transit stations to ensure 24-hour vitality in the station areas. So the indicator was calculated through formula (3-1) (Bertolini, 1999),

$$S4 = 1 - \frac{(\frac{a-b}{d}) - (\frac{a-c}{d})}{2} \tag{3-1}$$

Among them, a = max(S1, S2, S3); b = min(S1, S2, S3); c = (S1 + S2 + S3)/3; d = S1 + S2 + S3.

Due to the unavailable data, the functional mix only use the number of economic entities. This is one of the limitations of the research.

All the required data and sources are listed in Table 6.

Table 6 Data and sources

No.	Data	Type	Description	Time	Source
1	Boundary of Beijing districts	Polyline (shp)	Boundaries of each district with the attribute of the name.	January 2020	Geospatial Data Cloud (https://www.gscloud.cn/)
2	Road network	Polyline (shp)	All types of the road, including the primary, secondary, pedestrian, cycle lane, motorway, etc.	February 2020	OpenStreet Map (http://download.geofabrik.de/asia/china.html)
3	POI data	Point (shp)	Including all the Point of Interest in Beijing, such as the parking lot, government agencies, bus stops, entrances or exits of the metro station. Each item contains coordinate information, name, type, address, telephone number, neighbourhood, etc.	January 2020	Gaode Map (http://amap.com/)
4	Traffic	Point (shp)	Including the traffic signals, crossings, services, etc.	February 2020	OpenStreet Map (http://download.geofabrik.de/asia/china.html)
5	Panoramic image	Online image	It captures real-world scenes through professional cameras and uses software to stitch multiple planar photos together, to simulate a 360-degree panoramic landscape, which can	May 2015, June 2018	Baidu Map (http://map.baidu.com/)

			realistically represent the real scene.		
6	Population	Excel	The population information at the neighbourhood level.	2010	Beijing Municipal Bureau of Statistics (http://tjj.beijing.gov.cn/tjsj/yjdsj/rk/2020/index.html)
7	Real-time population	CSV	A heatmap layer of the real-time population.	April 2020	Baidu Map (http://map.baidu.com/)
8	Street index	Online map	It is a platform that shows the walking index and cycling index based on open-source data.	January 2020	CityDNA (http://demo.citydnatech.com/streetmapping/)

3.3.3. Processing the indicators

In order to make the two indices at the same measurement scale, the indicators were standardized by the Min-Max scaling, transferring the indicators in different units or magnitudes to 0-1. The positive indicators were transferred using formula (3-2),

$$x' = 1 - \frac{Max - x}{Max - Min} \tag{3-2}$$

Among them, x' is the standardized value, x is the original value of the indicators, Max is the maximum value of the indicators, Min is the minimum value of the indicators. While the negative indicators were calculated by the formula (3-3),

$$x' = \frac{Max - x}{Max - Min} \tag{3-3}$$

To more intuitively compare the dynamic changes of the station areas from 2015 to 2020, the values of all indicators of these two years were standardized as a whole data set, rather than two independent entities.

3.3.4. Identifying TOD typology

The way of identifying TOD typology is the node-place model proposed by Bertolini. According to the score of each indicator and sub-dimension in Table 5, two indices were formulated which represents the properties of node and place of each station areas. Then, a scatter plot was made and all the station areas were positioned in a chart. Based on the positions of 5 ideal types in the node-place model to identify the different types of station areas.

4. RESULTS

This chapter mainly addresses the fifth research objective. First, the compiled data was applied to the node-place model, the results are shown in the first section. Then, the compiled data for 2015 set was added in the model, to analyze the temporal change between 2015 and 2020. The results were visualized using the sunburst chart.

4.1. Application of the node-place model

The station areas are positioned in Figure 12 based on the values of their node index and place index. In general, most of them are close to the diagonal line as they have relatively equal values on node and place. While several station areas are far away from the diagonal line, their performance on the node or place function is much higher than on the other.

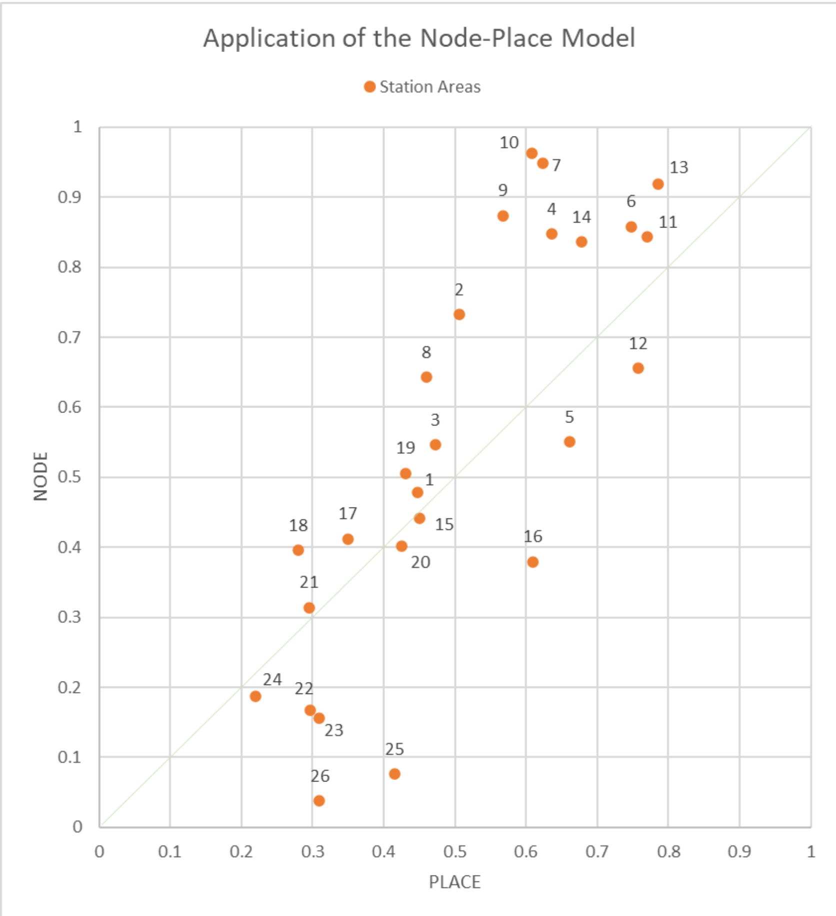


Figure 12 Application of the node-place model to the station areas of Beijing Metro Line 6 in 2020

Figure 13 shows the metro stations and lines currently in operation in Beijing. Figure 14 shows the location of the stations and the functional zones. It can be seen from Figure 12-14, transfer stations (e.g. 10, 7, 13, 9, 6, 4, 11, 14, 2) and stations not far from the city centre (e.g. 8, 12) perform better in the node function, while the stations located in the sub-centre area show very low node values (e.g. 22, 23, 24, 25, 26). In terms of the place function, high place values occur in the station areas near the CBD (Beijing Central Business District) (e.g. 13, 12, 11, 14) and some close to the city centre (e.g. 4, 5, 6, 7, 9, 10), station areas far away from the city centre (e.g. 24, 18, 21, 22, 26, 23) have low place values.

Figure 13 Beijing metro lines and stations in 2020
(Source: Beijing subway (https://www.bjsubway.com/station/xltzs/))

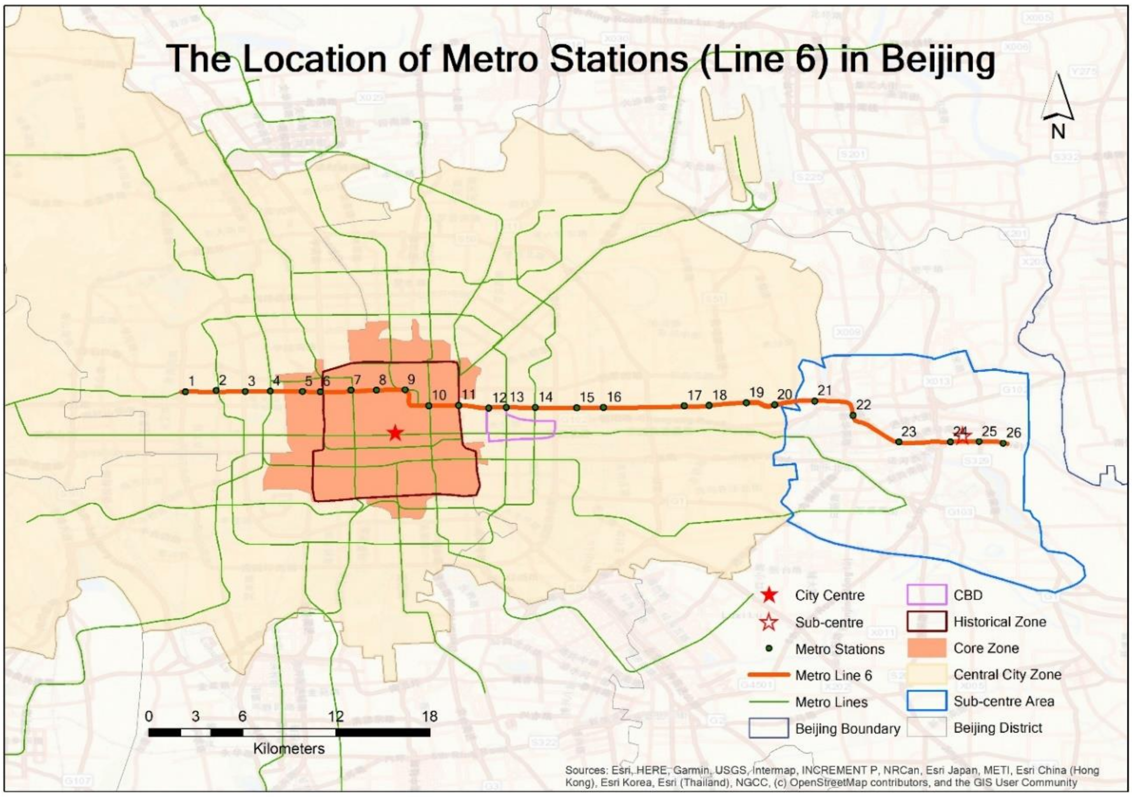


Figure 14 The location of metro stations (line 6) in Beijing

4.1.1. Stressed station areas

In the upper right corner of Figure 12, the station areas of Hujia Lou (13), Chaoyang Men (11) and Chegong Zhuang (6) are located in the stressed area. Both the intensity of the transportation flows and the diversity of urban activities within the station area are highest, the node values are higher than the place values in particular. All of these three stations are important transfer stations and are close to the city centre. So they have very high values of indicator N1 and N5. Located in a dense metro transit network, these station areas can be reached by more stations travel by metro, so the values of indicator N3 are higher than the average. Having high-quality roads, dense road networks and connecting bus lines, more than 50,000 people live in these station areas, the high place values can be explained. Among them, Hujia Lou Station and Chaoyang Men Station are located in the edge of CBD, with large concentrations of high-end enterprises, commercial and business facilities. Within the Chegong Zhuang station area, Beijing Xicheng culture creativity centralization area was established there to promote the development of the culture industry in the capital city. Therefore the values of *diversity* are higher than the average.

Figure 15 illustrates the indicators of Hujia Lou station area in a sunburst chart. It has the highest node value, as it is a transfer station of two metro lines with 8 exits, the average daily passenger volume is very high. One of the exits is directly connected to the BRT (Bus Rapid Transit) station, as is shown in Figure 16. Therefore, it has the highest values of indicator N2, N3 and N5.

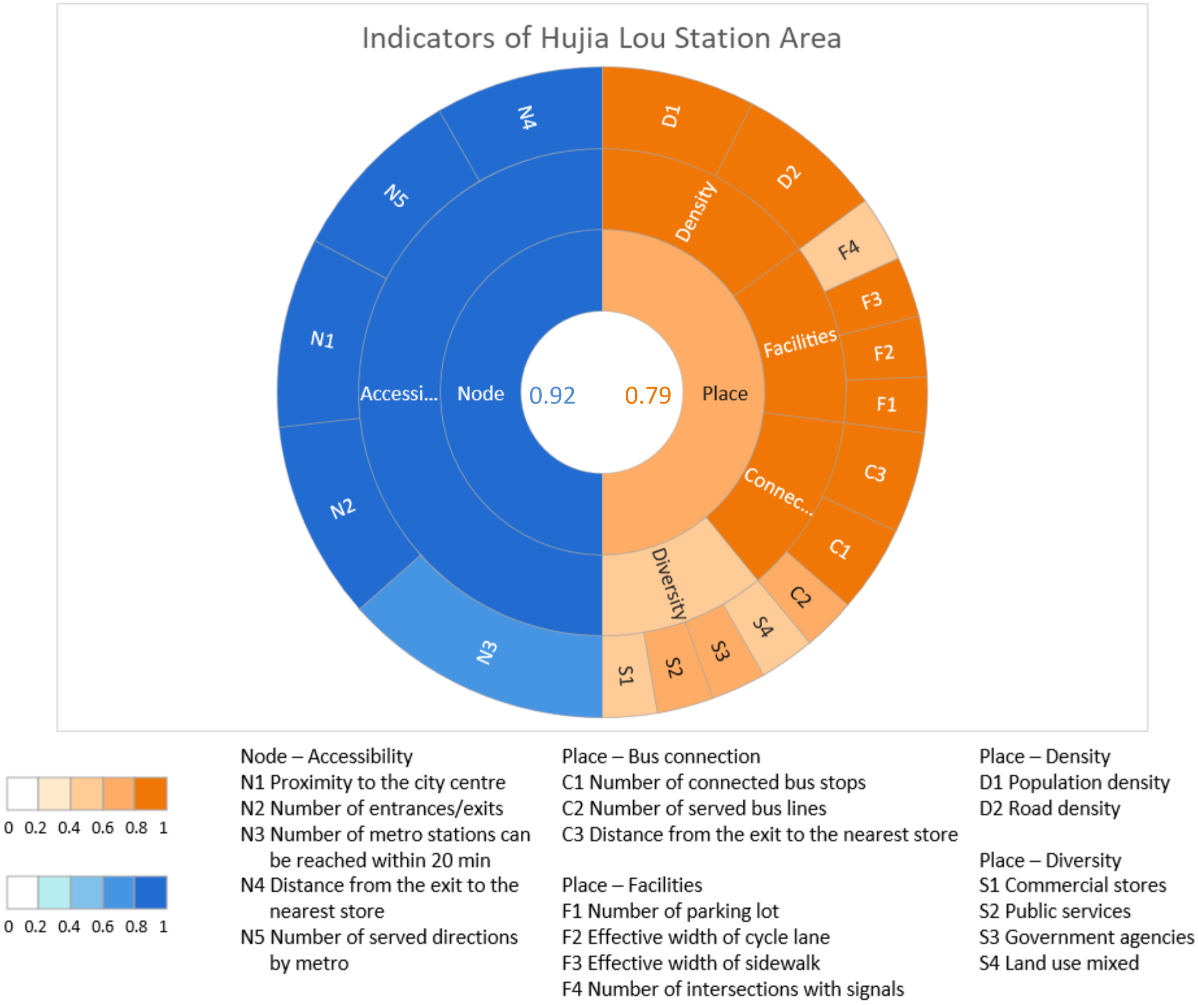


Figure 15 Visualization of the indicators of Hujia Lou station area in 2020


Figure 16 The exit is connected to the BRT station Figure 17 Wide paved cycle lane
(Source: Baidu panoramic image (http://map.baidu.com/))

At the same time, there are 12 bus stops and 32 served bus lines within the station area, a station of the "special bus line 1" is located 300 meters away from the metro station, this customized bus line passes through large residential areas and long-distance bus stations for passengers to and from Beijing South Railway Station. The high quality of cycle lanes and sidewalks makes the highest values of indicator F2 and F3 (see Figure 17 & 15).

4.1.2. Balanced station areas

When moving to the middle of the diagonal line in Figure 12, Chang Ying (19), Huayuan Qiao (3), Shili Pu (15), Haidian Wuluju (1), Cao Fang (20) are examples of balanced station areas. The development of node and place in these station areas is relatively balanced and at a moderate level. All of these stations are not a transfer station and within the central city zone, so the values of indicator N5 of these station areas are lower than the average. Haidian Wuluju Station and Huayuan Qiao Station are located 12.6 and 7.5 kilometres west of the city centre, respectively. Shili Pu Station is located 9.1 kilometres east of the city centre. Since Huayuan Qiao and Shili Pu Station are not particularly far from the city centre, the values of N1 are slightly higher than the average, N3 are slightly lower than the average. Chang Ying and Cao Fang Station are located about 18 kilometres east of the city centre, the values of N1 are lower than the average. There are no other metro lines around, only 10 stations can be reached by metro within 20 minutes. But the exits of these two stations are very close to the commercial stores or shops, so the values of N4 are higher than the others.

For the place function, most indicators are near the average. Among them, Haidian Wuluju, Huayuan Qiao and Cao Fang station areas have higher scores on *bus connection*. Compared with station areas far from the city centre, Haidian Wuluju and Huayuan Qiao station areas have a more developed road network, so the values of indicator D2 are on the average. With the high population density of 43,000 people per square kilometre, the value of D1 of Shili Pu station area reaches the highest.

The average node and place scores of all the station areas are 0.53 and 0.47 respectively. The scores of HuaYuan Qiao station area are just at the average, as is shown in Figure 18. As a single line station with 6 exits, it is more than other stations and the value of N2 is higher than the average. It is an important transit node because it is located on the Third Ring Road, there are 12 bus stops and 29 bus lines connected to the metro station. Since this urban expressway passes through the station area, there are only 4 signalized intersections, which leads to a very low value of F4. Besides, S2 shows a significantly high value because of the gathering of a university, elementary school and various educational institutions. However, it is worth noting that catering and commerce are not very developed in this area, which successfully attracted investment last year. A special food street has just opened recently, and many canteens are still under construction.

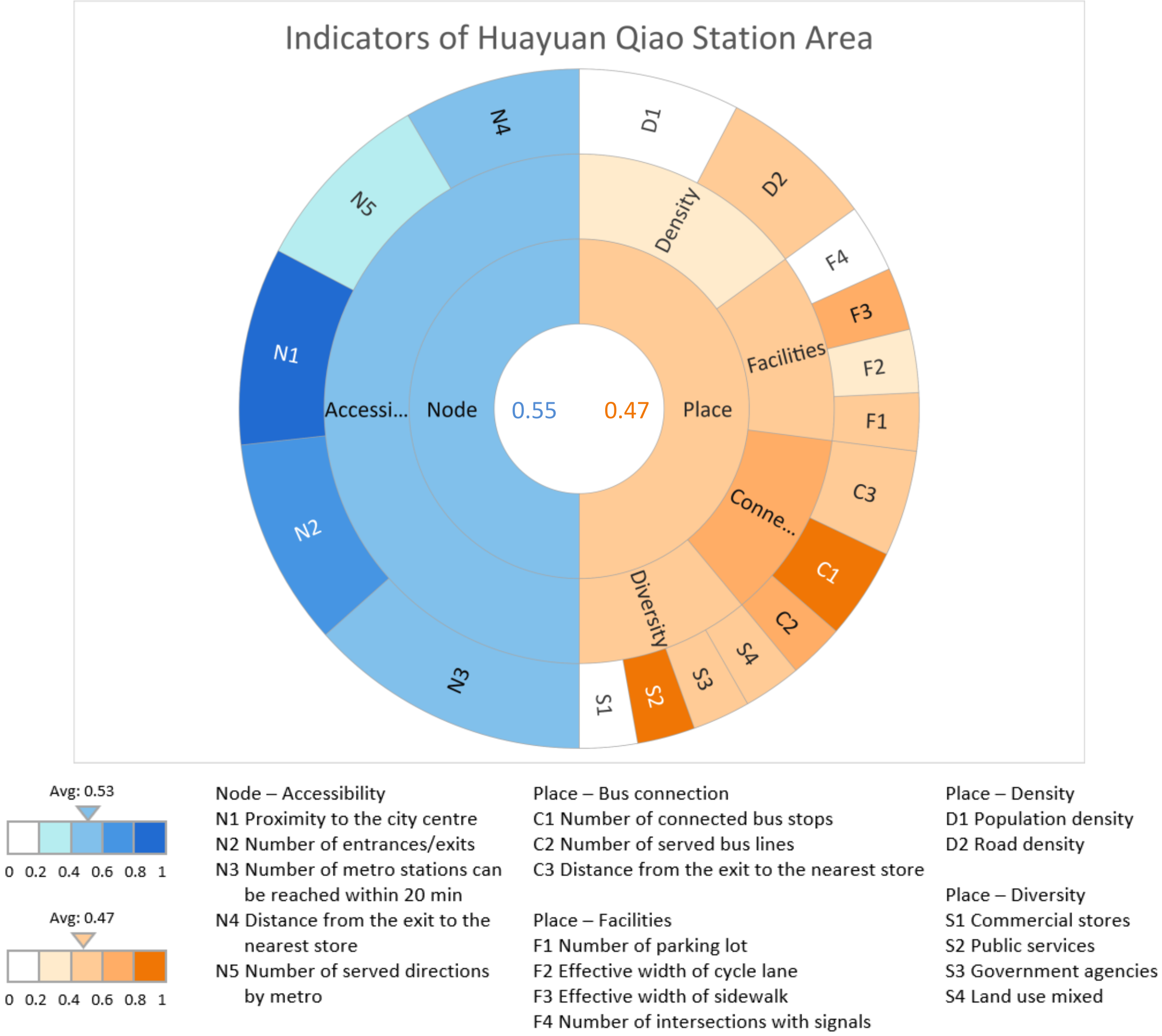


Figure 18 Visualization of the indicators of Huayuan Qiao station area in 2020

4.1.3. Dependent station areas

In the other extreme position, Tongzhou Beiguan (22) and Haojia Fu (24) are the examples of dependent station areas (see Figure 12). Neither the accessibility of the station nor the diversity of activities has been fully developed. These areas are all located in the sub-centre area, many infrastructures are still under construction. Due to the fact that these stations are close to the east end of the line, and they have no access to other metro lines, the node values of these station areas are low, especially for the terminal station Lu Cheng (26), N1, N3, N4 and N5 of Lu Cheng station area are the lowest values. Besides, the average distance of 2.2 kilometres between these stations is longer than that between those stations that are within the central city zone, which is another cause of low accessibility.

Haojia Fu station area has the lowest place value, as is shown in Figure 19. Although there are residential areas in the station area, the population density is less than 5000 persons per square kilometre. Other social activities are not very developed. The Beijing Municipal People's Government and other municipal administrative centres have moved to the sub-centre area, within the Haojia Fu station area. Other infrastructure is constantly being built. The relatively good performances in the place function are the effective width of cycle lanes and sidewalks. Because of the newly constructed roads in these two years, both indicators of F2 and F3 perform well.

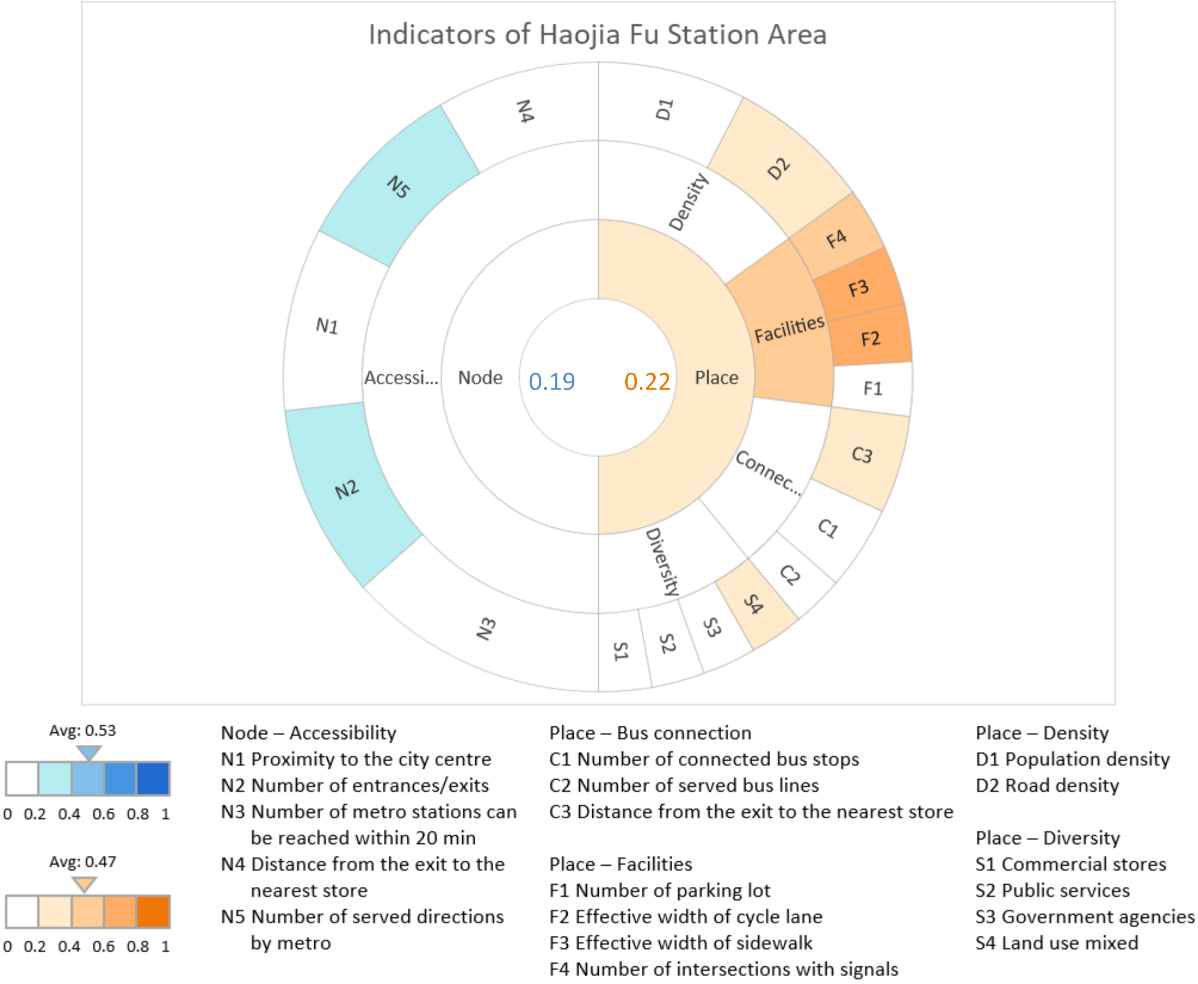


Figure 19 Visualization of the indicators of Haojia Fu station area in 2020

4.1.4. Unsustained nodes

Unsustained nodes refer to those station areas positioned in the left of the diagonal line, where the node value is much higher than the place value. This imbalance occurs at most of the interchange station (e.g. 14, 4, 7, 10, 9, 2) and is located in the historical zone (e.g. 7, 8, 9, 10).

Ping'an Li (7), South Luogu Lane (9) and Dongsi (10) are the interchange stations within the historical zone. As transfer nodes, those stations are very close to the city centre and in a dense metro line network, it means that they are easily accessed by more stations. For these station areas, the node function performed very well, but in terms of place function, the land at these station areas has not been utilized with maximum intensity. The low density of population and social activities are the main reasons for lowering the place value. To maximize the protection of the remaining architectural buildings, the historical zone is under the direct jurisdiction of the central government. Due to the requirement of decentralization of the non-capital functions of Beijing and control the population, some low-end stores and wholesale markets have been gradually phasing out. Although Beihai North (8) is not a transfer station, it has the lowest function values compared with other station areas in the historical zone. The population density is only about 5000 persons per square kilometre.

The sunburst chart in Figure 20 shows the indicators of Dongsi station area. It is the most unsustained node because it has the largest difference between node and place function. As is shown in Figure 20, it has the best node function with a maximum value of 0.96. However, the place index is only 0.61, which is not as high as the node index. As the nearest interchange station from the city centre, it has 7 exits and 66 stations that can be reached within 20 minutes, which gives it the highest values of indicator N1 and N5. On the other hand, there is no large shopping mall or high-end office building, while education and medical infrastructure are relatively complete. Many government agencies are concentrated in this area, therefore, the S3 reaches maximum. Characterized by the low-rise and high-density houses (Figure 21 & 22), the traditional residential areas siheyuan (courtyards) and Hutong (alleys) are located northeast of the station, which were developed on the most prosperous streets and lanes in the Yuan Dynasty. After 700 years of changes, the buildings at that time and the layout of the streets are still preserved. The population density within this area is only about 10,000 persons per square kilometre.

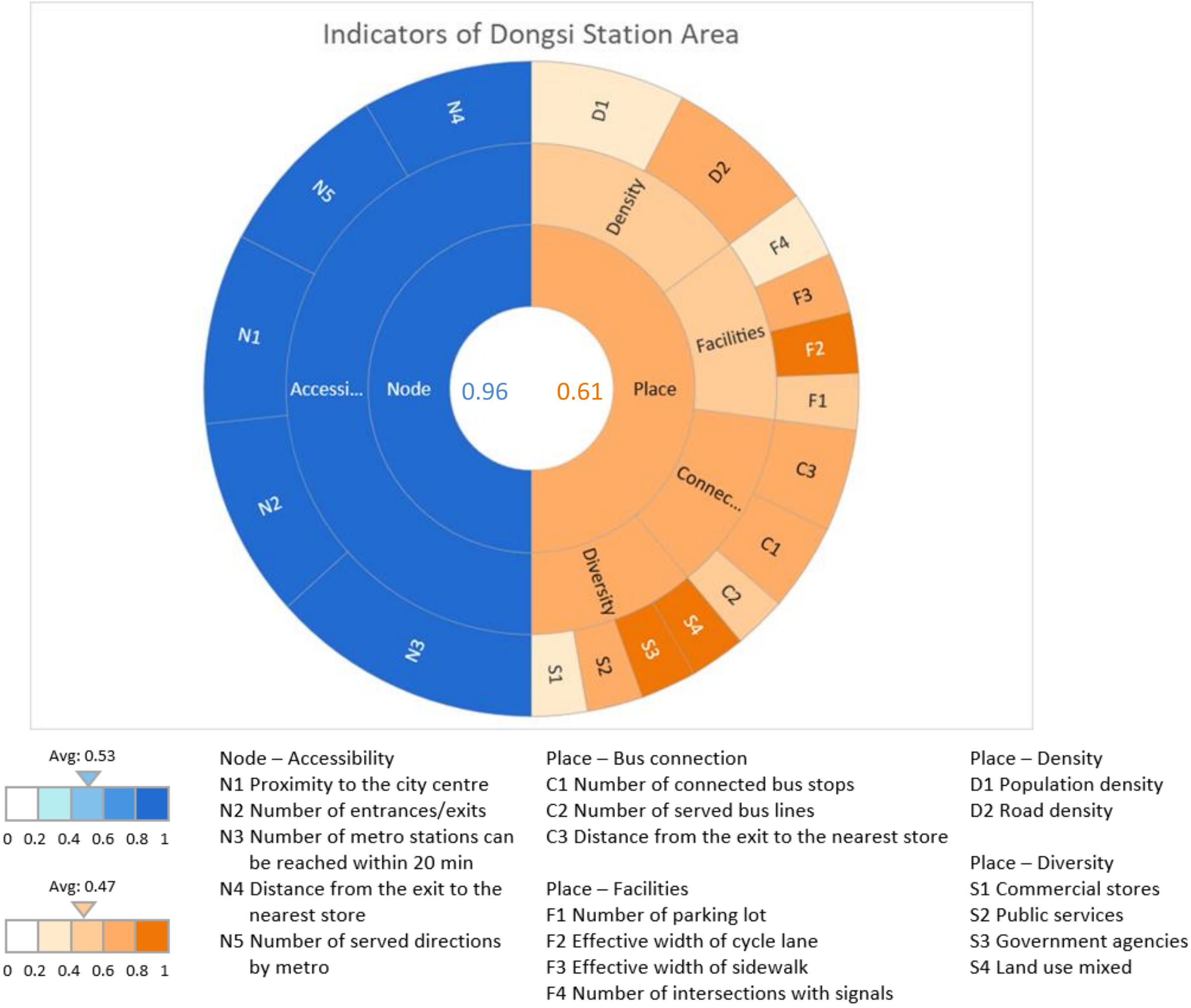


Figure 20 Visualization of the indicators of Dongsi station area in 2020

Figure 21 Hutong in Dongsi station area

Figure 22 Lishi Hutong in Dongsi station area

4.1.5. Unsustained places

Unsustained place station areas are distributed to the right of the diagonal line. These stations show a stronger performance on the various social activities than on the transport flow. The station areas of Dongda Qiao (12), Chegong Zhuang West (5), Qingnian Lu (16) are examples of unsustained places. The connectivity of these stations is not as good as the transfer station, so the node values are lower and at a moderate level. Since they are non-interchange stations with 3 or 4 exits, the values of N2 and N5 are lower than the average, the connectivity of these stations are not as good as other stations. On the place side, these areas are well developed, most of the indicators are higher than the average.

Located in the very developed CBD area, Dongda Qiao station area has the third-highest place value. As is shown in Figure 23, in addition to catering and shopping centres, international schools, hospitals and other institutions are also located there, S1 and S2 of Dongda Qiao station area have reached the maximum. With sufficient parking lot, wide cycle lanes and sidewalks, it has a good performance on *facilities*. Around 50,000 residents live there, so the population density is relatively high.

For the station areas within the sub-centre area (e.g. 23, 25, 26), the transport flow is at the lowest level and there are not enough social activities. However, the sidewalk and cycle lane are almost not occupied by private cars. Due to newly constructed roads in recent years, there is little congestion. Medium or higher value of *bus connection* is another reason for increasing the place value.

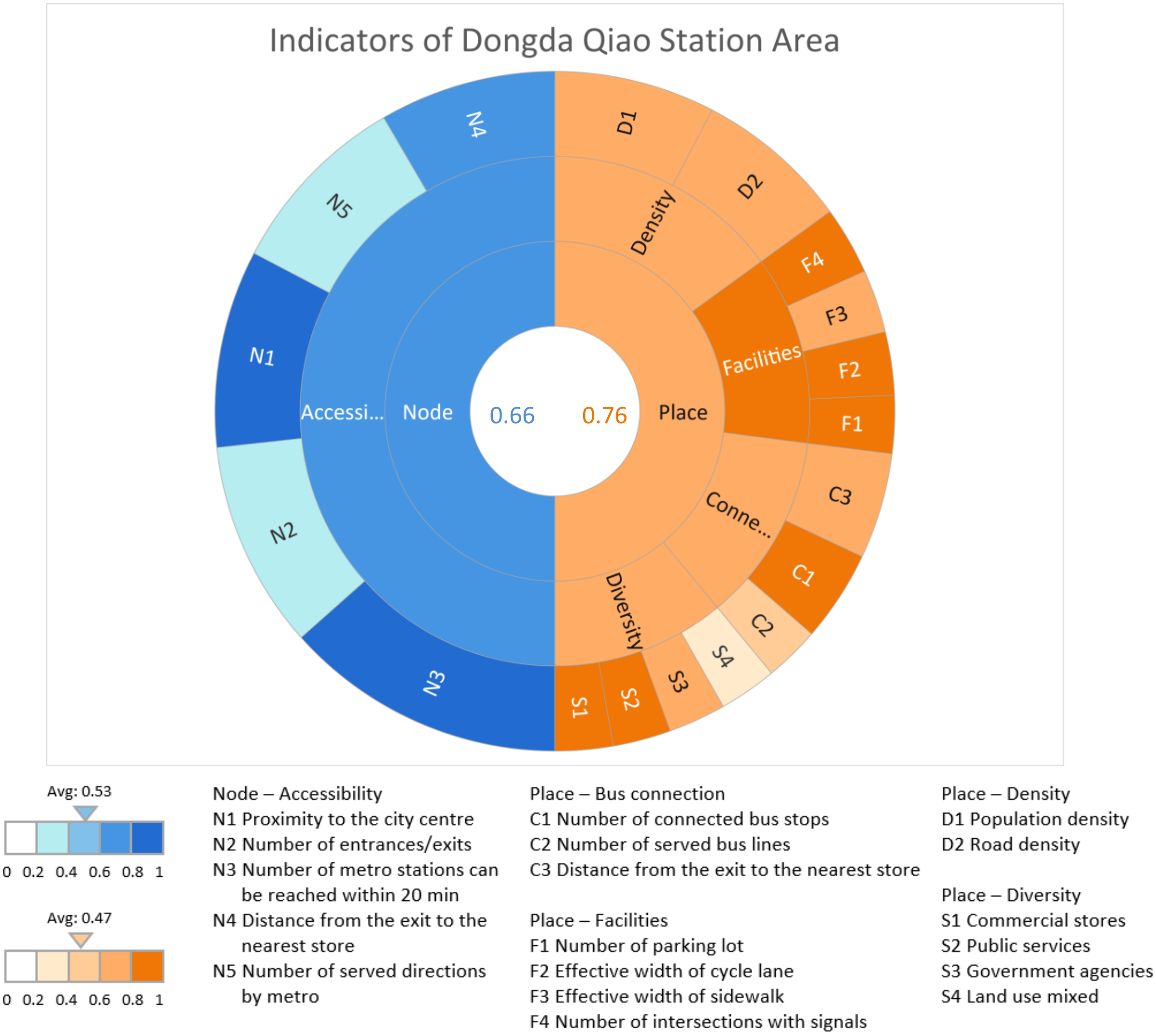


Figure 23 Visualization of the indicators of Dongda Qiao station area in 2020

4.2. Temporal change between 2015 and 2020

The same model was applied to the 2015 dataset, Figure 24 illustrates the change of station areas in the 2015-2020 period. Generally, most of the station areas are moving towards the middle diagonal line, that is, developing balance. The increase can be seen in both the node axis and the place axis. The node values increase can be explained by the fact that a new metro line was connected to the station, or several new stations were opened nearby the station so that the accessibility by metro has improved. Figure 25 shows the metro lines and stations that were operated in 2015. For the obvious change of place value, the reasons are mainly from the improvement of road quality, population increasing and changes in land use types. Based on the paths of development, all the station areas can be classified as 8 categories, as is shown in Table 7 and Figure 24. Upgrading is more likely to be a balancing way than downgrading.

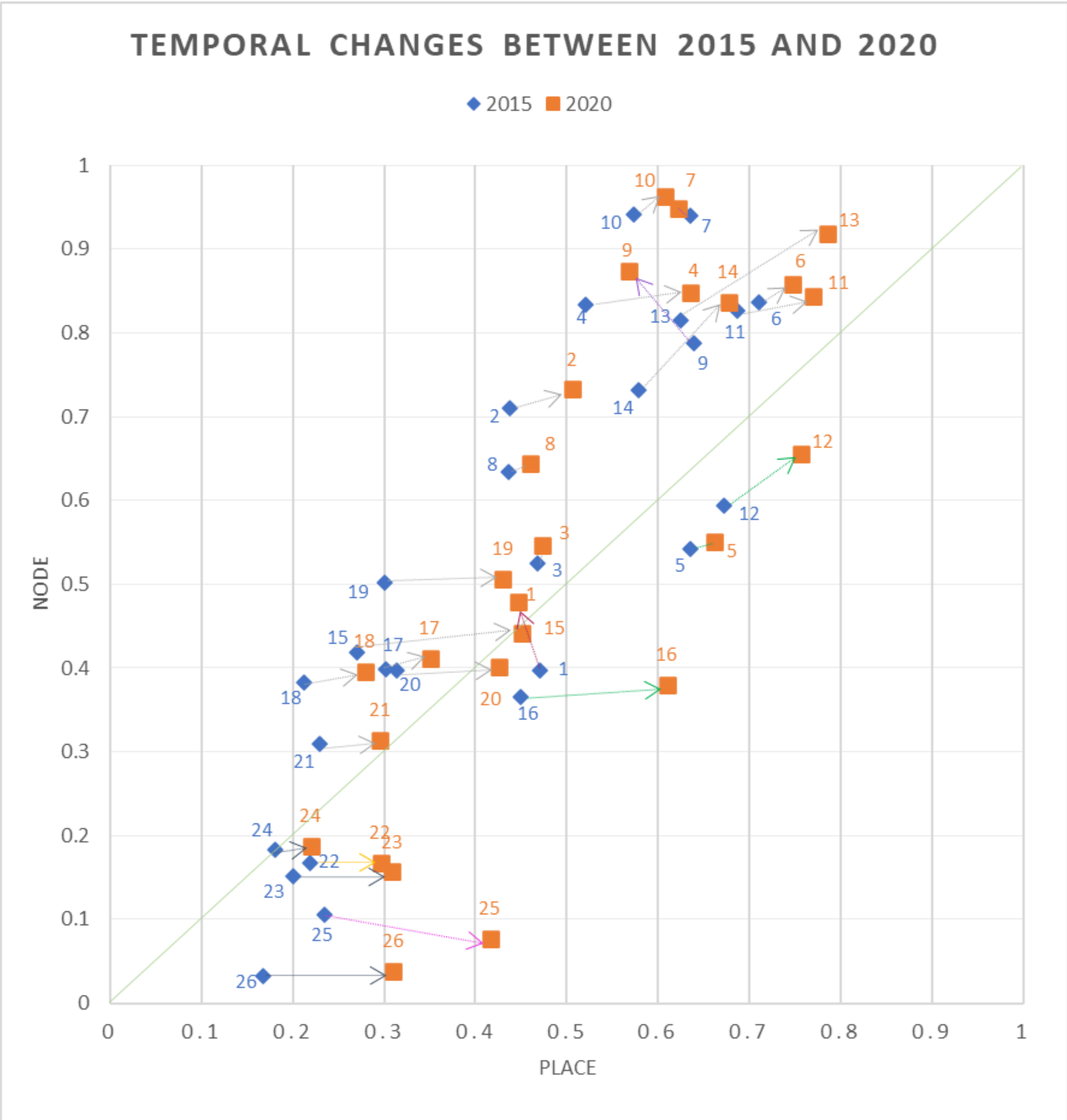


Figure 24 Temporal change of station areas between 2015 and 2020

Table 7 Trends of development

Station area category in 2015	Trend of development: Node function	Trend of development: Place function	Station areas	The direction in Figure 24
Unsustained place	↑	↓	1	↖
Unsustained node	↑	↑	5, 12, 16	↗
	↑	↑	2, 3, 4, 5, 6, 8, 10, 11, 13, 14, 15, 17, 18, 19, 20, 21	↗
Dependence	↑	↓	7, 9	↖
	–	↑	22	→
	↑	↑	23, 24, 26	↗
	↓	↑	25	↘

Figure 25 Beijing metro lines and stations in 2015
(Source: Beijing subway (https://www.bjsubway.com/station/xltzs/))

It is proposed that node and place functions should be in balance, the station areas performing in one aspect better than another (unsustained place and unsustained node) should be further discussed. According to the description of Bertolini (1999) and Reusser et al. (2008), there are three idealised paths for an unsustained node to approach the balance (see Figure 26). First is to decrease the node function (e.g., reducing the frequency of services.). Alternatively, the second way is to increase the place function (e.g., establishing new public services near the station). Combined these two is the third way. While the opposite methods are applied to the unsustained places. From Figure 24, it can be seen that not all the station areas are moving towards an “equilibrium”, except for the 6 paths mentioned above, several station areas have completely different development paths (e.g. 9 & 16).

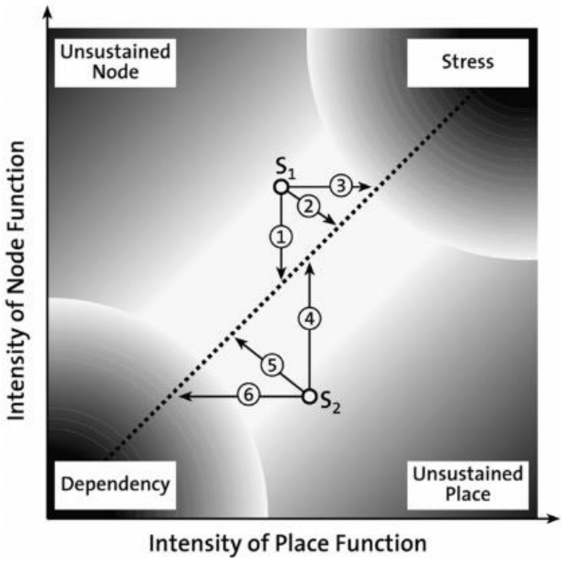


Figure 26 Potential developmental paths for S1 and S2 (S1 and S2 are exemplary stations)
(Sourcce: Reusser et al. (2008))

4.2.1. Unsustained places

All the station areas in this category have improved in node function. Among them, Haidian Wuluju (1) station area has reduced the place value and tends to balance. The station areas of Chegong Zhuang West (5) and Dongda Qiao (12) have a certain degree of improvement in both aspects. The development of the Qingnian Lu (16) station area deviated from balance, the improvement in the place function is far greater than the node function.

4.2.1.1. Imcreasing node function and reducing place function

By improving node function and reducing place function, Haidian Wuluju station area has developed from an unsustained place to a balanced station area (following path 5 in Figure 26). Haidian Wuluju station was the terminal of Line 6 in 2015. Since the west extension line opened in 2018, Haidian Wuluju Station no longer serves as the terminal (see Figure 25). The values of N3 and N5 have increased (see Figure 27). Its node function will still increase in the future because it is planned to be the terminal of the metro line 12 which is under construction.

From Figure 27, the changes on place dimension can be seen in the sub-dimension of *density*, *diversity* and *facilities*. Because of the remaining Jingmen Railway, residents and cars had to cross a 1.8-meter-high culvert, which caused great inconvenience for travel. In 2019, the culvert was replaced by a 40-metre wide road, connecting the north and south, as is shown in Figure 28, the road density (D2) increases. Moreover, illegal grocery stores with more than 10,000 square metres were demolished and replaced by a Jingmen Railway Park (see Figure 29), including the basketball courts, entertainment facilities and senior activity centres, so S1 decreases, S2 and S3 increase. Furthermore, in the north of the park, a project combines high-tech industry innovation parks, commercial streets and plazas have emerged, covering a variety of business formats including banking, education, energy, catering and retail, to create a new landmark.

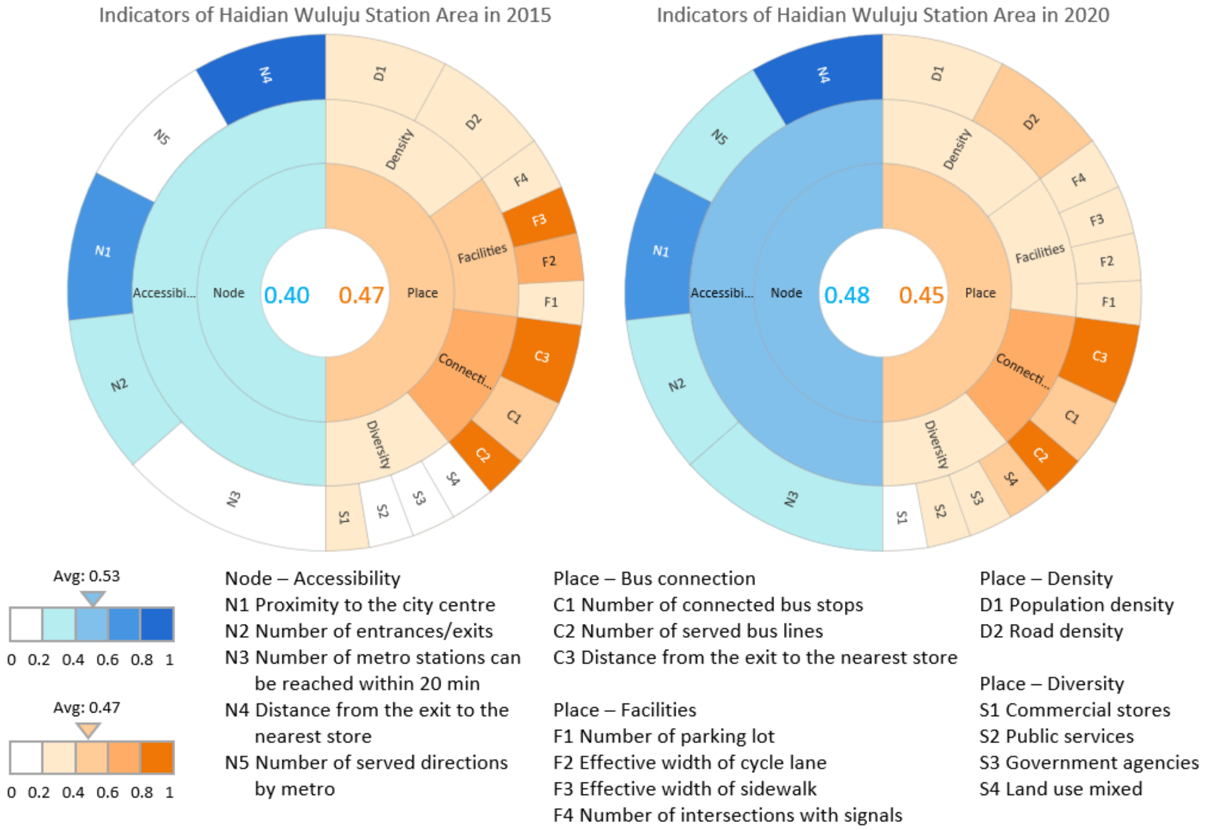


Figure 27 Temporal change of Haidian Wuluju station area between 2015 and 2020

(a) 2015 (b) 2020

Figure 28 Wuluju South Street was constructed in 2019

(Source: Faxian Beijing (https://www.sohu.com/a/337093306_120209831))

(a) 2015 (b) 2020

Figure 29 Jingmen Railway Park

(Source: Baidu Railway Bar (https://tieba.baidu.com/p/5823125291?red_tag=1488810580&traceid=), Faxian Beijing (https://www.sohu.com/a/337093306_120209831))

4.2.1.2. Increasing both node function and place function

The other three station areas have improved in both node function and place function, but Qingnian Lu (16) station area has significant improvement in place function. Qingnian Lu is about 10 kilometres away from the city centre and is located between the East Fourth Fing Road and Fifth Ring Road. Compared with the other areas adjacent to it, the node value is slightly lower, this is because it has only three exits. The real estate developer connected to one of the four exits in the original plan did not agree with the plan, so this exit has not been opened, and it is possible to be permanently cancelled.

At first, the area around Qingnian Lu station was not the key point for development, and it was called "back garden of the CBD" because it is located in the northeast of the CBD and nearly 50% of the population was living in the high-end residential area. However, as the number of enterprises entering the CBD area is close to saturation, the CBD area expands eastward, and the development centre of Beijing moves eastward, this area has more than residential functions. The place close to the large commercial complex is very prosperous. Not only has the business developed, but also high-end office buildings and cultural industries have been attracted, S1, S2 and S3 have increased (see Figure 30). The Qingnian Lu area has formed a business circle that integrates residence, commerce and business. The functional positioning of this area gradually transformed into the CBD business service area.

In addition to the *density* and *diversity*, the sub-dimension of *facilities* has also improved, as shown in Figure 30, especially for the cycle lanes, they are physically isolated by guardrails, so there is no phenomenon of car occupation, see Figure 31.

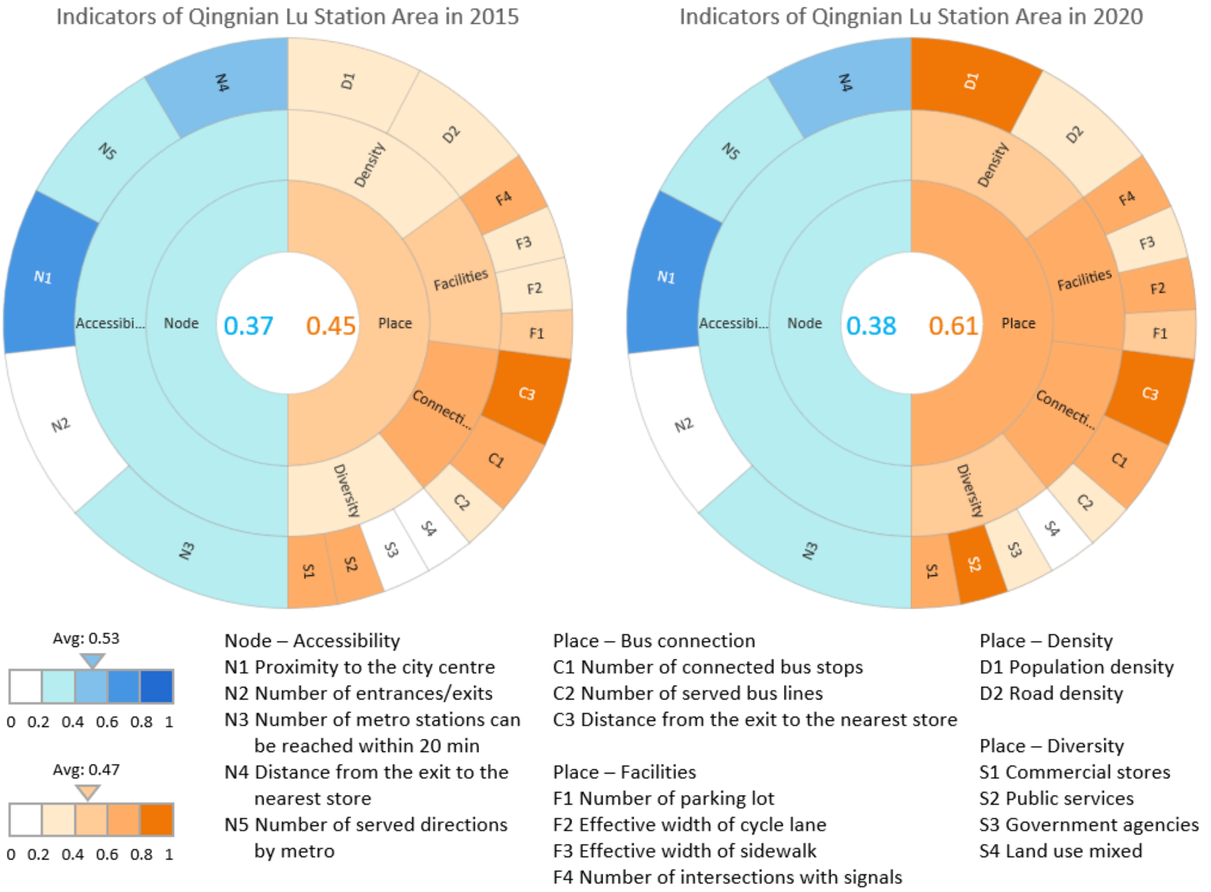


Figure 30 Temporal change of Qingnian Lu station area between 2015 and 2020

(a) 2015 (b) 2020

Figure 31 The improvement cycle lane near Qingnian Lu station
(Source: Baidu panoramic image (http://map.baidu.com/))

4.2.2. Unsustained nodes

The newly connected metro stations and lines have improved the accessibility of most stations, so the node values have been increased to varying degrees. Most of the station areas have improved in the place function and close to the diagonal line, but the place values of Ping' an Li (7) and South Luogu Lane (9) station areas have decreased.

4.2.2.1. Increasing both node function and place function

As the new lines were connected to the stations South Luogu Lane (9) and Jintai Lu (14), there is the biggest improvement in N3 and N5. It has some influence on the accessibility of the other station areas around them. In general, the main reason for the improvement of place function is the increase in population and road density, especially for station areas far from the city centre. Declining population density can be seen at all the station areas located in the historical zone, but there are some improvements in the two sub-dimensions of *facilities* or *diversity* (e.g. 7, 8, 9, 10). Second, the improvement of *diversity* can also be seen in many station areas, as the number of different services has increased. Many low-end stores or industries have been migrated or upgraded due to the requirement of non-capital functions relocating, which is reflected in the decline of some indicators in *diversity*. In the sub-dimension of *facilities*, the number of parking facilities has basically increased, the effective width of cycle lane and sidewalk has also increased to a certain extent, but there are also cases where they are reduced due to occupation. The change in *bus connection* is relatively small, there were one or two new lines opened for the station areas within the central city zone, but there is not much change in the value of the indicator. There are certain changes to the station areas in the sub-centre area, because of the temporary bus stations or newly opened bus lines.

Chang Ying (19) was an unsustained node in 2015, through increasing the intensity and diversity of the activities around the station, it has become a balanced station area. The node value of this station area is higher than that of other single-line station areas because it has 7 exits and all of them are directly connected to the underground floor of the nearby buildings. Because the station is far away from the city centre, the newly built metro lines and stations have little effect on its transport function. As is shown in Figure 32, the main improvement occurs on the sub-dimension of *density*. The station area is within the Chang Ying community, which is located in the easternmost part of the central city zone. At first, Chang Ying community was the place where the Hui ethnic minority people lived. As the opening of the large commercial complex in 2015 and the development of the real estate, it attracted a large population. Now the population density of the community is more than 10,000 persons per square kilometre (D1 has greatly improved). In addition to meeting people's high-end consumption needs, early education centres and family fun parks have also increased significantly. Commercial shops on the ground floor in residential communities have also developed instead of the shops with ethnic characteristics. Because of attracting a large number of customers also from the outer suburbs, there is an insufficient supply of parking spaces, the cycle lanes and sidewalks are occupied.

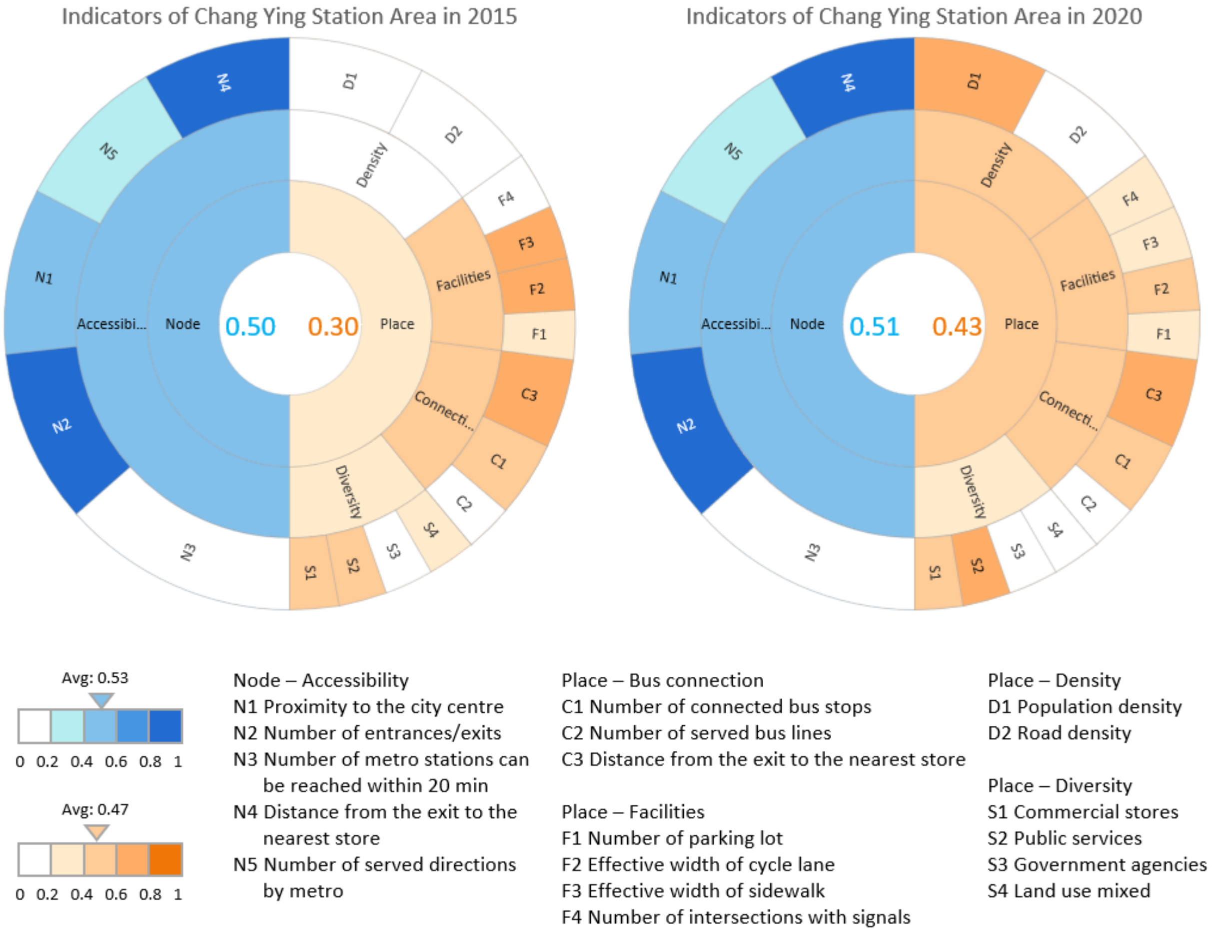


Figure 32 Temporal change of Chang Ying station area between 2015 and 2020

4.2.2.2. Increasing node function and reducing place function

In 2015, the node function of the station areas of Ping' an Li (7) and South Luogu Lane (9) was relatively stronger than the place functions. However, in 2020, their node function was improved, the place function was reduced at the same time. They seem to be developing more unsustained.

The increasing accessibility of South Luogu Lane reflected in the increased N3, N4 and N5, it can be explained as the newly opened shops near the exit. Also, there are two stations along another transfer metro line were not opened for operation in 2015, this also has a certain effect on Ping' an Li station area.

For the decreasing place value of these two station areas, the main reason is the decreased population density. Population relocation is the most important in the action of functional dispersal in the historical zone. Only when the resident population decreases, can there be more space to improve the quality of living condition and reconstruct the historical buildings.

South Luogu Lane is the oldest preserved neighbourhood in Beijing. It is famous for its history and culture, attracting a large number of tourists. Seizing the huge business opportunities, many shops developed along this lane. However, it not only caused environmental pressure but also had impacts on residents, In 2016, the government requested that this area be renovated to restore its residential function and reducing the number of stores from 235 to 154 (see Figure 33, S1 has reduced). The redeveloped lane has lost the strong commercial atmosphere and restored its original appearance. At the same time, the roads were redeveloped, and a multi-storey car park was built, the indicators of *facilities* have improved means that the improvement of people's quality of life.

From Figure 14 & 24, the station areas are within the historical zone (Ping' an Li (7), Beihai North (8), South Luogu Lane (9), Dongsi (10)) are all unsustained nodes. Because they are very close to the city centre and within a dense metro network, the accessibility of these station areas is very high, although the Beihai North station is not a transfer station, its node function is much higher than the place function in terms of numerical values. But in fact, the infrastructure and facilities in these areas are very complete, only because of the low density and low-rise of the buildings, they do not have advantages in scoring.

In the future, as the very important transit stations in the city centre, these stations may be connected with three metro lines. The node function will continue to be enhanced, how to make these station areas develop towards balance, and at the same time ensure that population is relocated, historical lanes are protected, and no expansion or the basements? Or in other words, have they reached their own "balance".

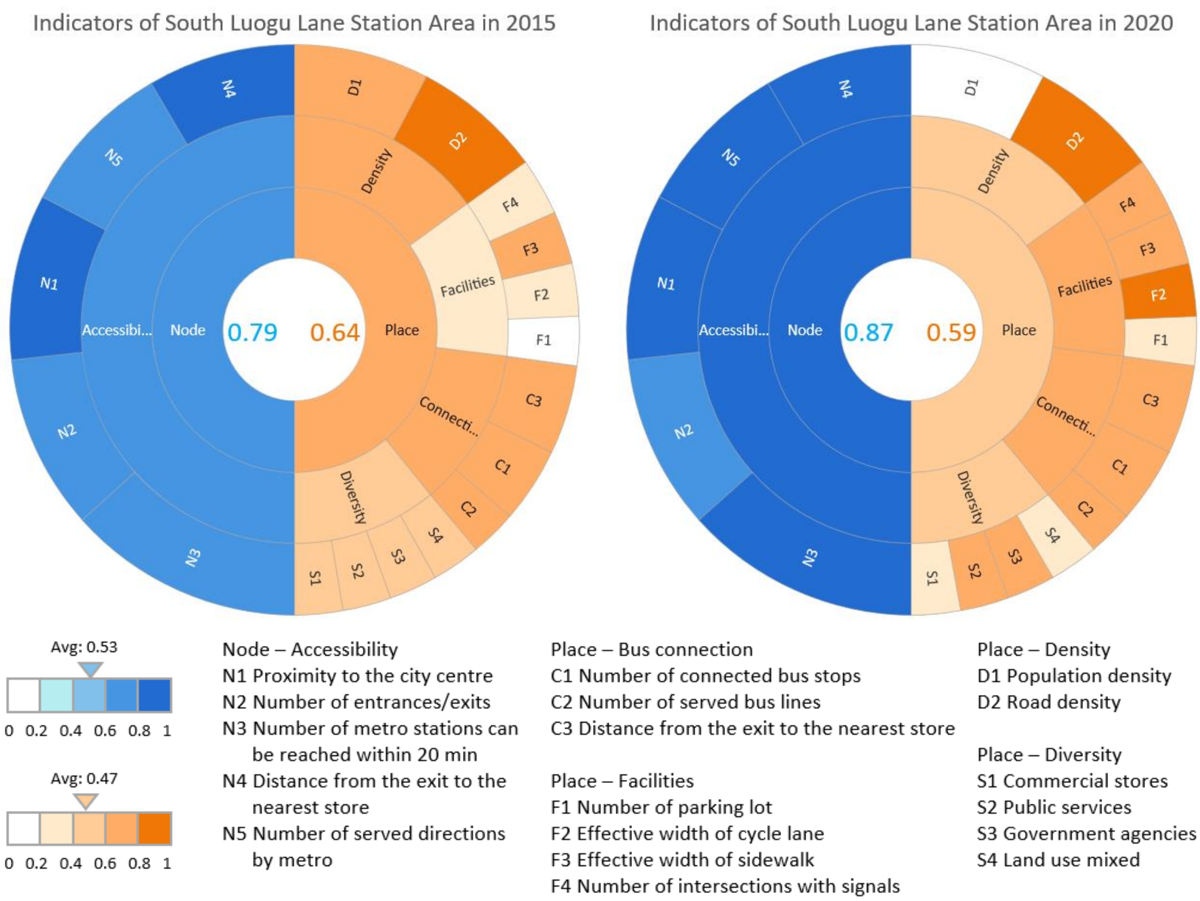


Figure 33 Temporal change of South Luogu Lane station area between 2015 and 2020

4.2.3. Dependent station areas

The station areas located in the sub-centre are classified as dependent station areas. After 5 years of development, there is a slight improvement in node function for some station areas (e.g. 23, 24, 26), but a significantly increased place value can be seen. It is mainly because of the increased road density and the high quality of cycle lane and sidewalk and, as is shown in Figure 34. This improvement can be seen in most of these station areas. However, there is still a lack of diverse and intense social activities in these areas so far.

(a) Cycle lane (b) Sidewalk

Figure 34 The newly constructed Yunhe East Street in the sub-centre area
(Source: Jidi Tekuai (https://www.weibo.com/u/1313897095))

Figure 35 shows the indicators of Dongxia Yuan station area. The node value of Dongxia Yuan station area decreased because one of the exits is currently under construction, only two exits are open. An integrated transportation hub next to Dongxia Yuan station has been constructed since last year. In the future, it will be a very important transit station for connecting the city centre and sub-centre, also the peripheral cities and Beijing. Besides, a population of over 1 million will be allocated in the sub-centre area, the corresponding facilities are also being established. It will develop towards a balanced station area.

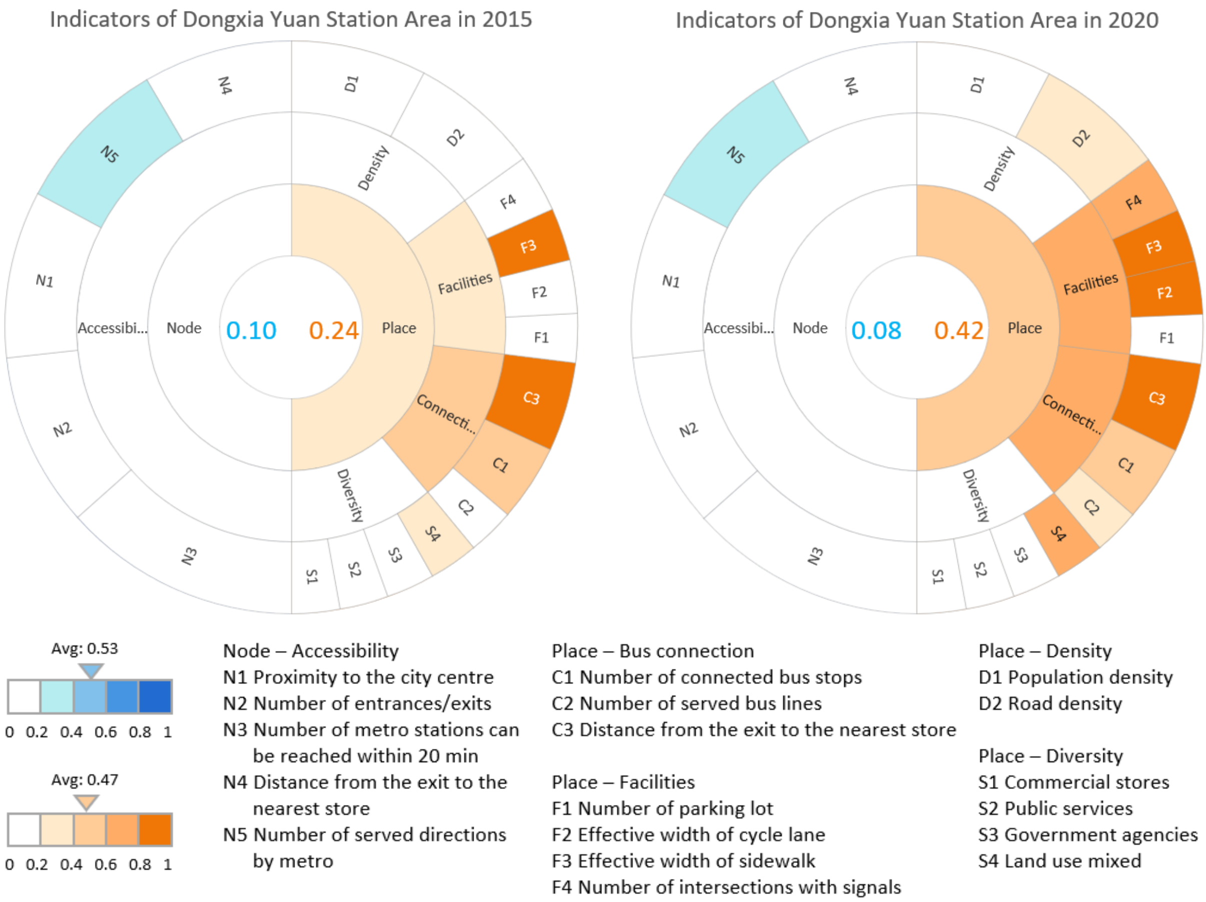


Figure 35 Temporal change of Dongxia Yuan station area between 2015 and 2020

5. DISCUSSION

From the perspective of the TOD concept, it has been successfully used in many applications in planning, design, transportation and policy. Since TOD is not only developing new towns along the traffic corridor, high-intensity development around the station, but also emphasizing the principle of "people-oriented" to deal with the relationship between the station and surrounding area, and to promote the common development of public transport and urban city. It is the highlight that it should apply to the specific context, the methods used and the strategies formulated should be consistent with local development.

Therefore, expert interviews were essential in this study. Because they have many years of work or research experience, they are more familiar with the context of Beijing, the more relevant information beyond research can be also obtained from them. This is one of the limitations of this study, the scores of each indicator were completely dependent on the knowledge, background and opinions of expert. In the future, other objective methods can be used to form the indices, and the results can be compared.

As for the indicator selection, "passenger frequency" has been discussed in some previous studies, it was used as a factor in the analysis of classification. However, Zemp et al. (2011) analyzed the influence of system context on system structures and argued that it does not sufficiently describe the stations, they assumed that the stations having similar passenger frequencies are not comparable. It is undeniable that passenger frequency does have a lot of information. According to the big data records, spatial-temporal analysis on passenger flow characteristics have been conducted by many researchers. In the process of expert interviews, passenger volume was considered to be the most important indicator with the highest score., although this indicator was not included in the research in the end. How does passenger frequency describe the characteristics of the station area is still worth discussing.

Another controversial indicator in this study is the number of signalised intersections. Experts have different attitudes towards this indicator. From the perspective of the development of dense road networks, the more intersections the better, but from the perspective of pedestrians, the more traffic lights, the more time it may take to cross the street. It is considered as a positive indicator in this study because the development goal for roads in Beijing is high density and small blocks. Therefore, it did not consider whether it is convenient for pedestrians.

This leads to the thinking of the dimension of the measurement TOD. It should be noted that the node and place are not the only dimensions of interest. As the other modified models, passengers' experience or satisfaction is also very important measurement aspects. It is worth noting that the node-place model was proposed based on the land use-transport feedback cycle. Although some modified models were considered to have more accurate results, they do not have a theoretical basis to support. It can be said that measuring more dimensions, the results can be better explained the reality. In terms of the number of travellers, customer satisfaction, retail turnover and real estate profits, it should be also seen as a validation of the node place model (Huang et al., 2018; Practice et al., 2006; Vaessens, 2005). It will be interesting to discuss the station area synergy and analyze the effects on the performance of the station areas.

The sunburst chart was used to visualize the results of each metro station areas, the motivation for selecting this diagram was to find a way to display the multi-hierarchical data simultaneously. Both the value of dimensions and individual indicators can be presented in a chart. Another limitation is the details cannot be displayed, for example, the values of 0.21 and 0.39 are presented as the same color, but of 0.39 and 0.41 can be distinguished. This shortcoming can be solved by using a gradual colour scheme, but it may be more difficult for the naked eye to distinguish colors that are too close.

Lyu et al. (2016) developed a TOD typology for all the metro station areas in Beijing using cluster analysis. The research systematically measured the station areas and it was helpful to have an insight on the city level. The quantitative method does not have a fixed number of categories, so different number of clusters may lead to different results. Each category does not have a very clear boundary and the difference in each category is still large.

This study offers a way of identifying the TOD typology for metro station areas in Beijing by node-place model and shows changes between 2015 and 2020, which reflects a certain direction of urban development and investment. It will be more convincing for discussing the results of the research during the planning process, such as the “unsustained station areas” within the historical zone are really unsustained? The results displayed by the model can reflect certain realities, the analysis of dynamic change can provide information for policymaking. Such as applying the successful experience of one station area to the redevelopment or upgrading of other stations with the same characteristics.

6. CONCLUSION

This study offers a contextual TOD typology for 26 metro stations along line 6 in Beijing. Based on the developed typology the changes between 2015-2020 are analyzed. Several studies have been conducted to identify the TOD typology in Beijing, but there are only one or a few factors used for classification, such as the passenger volume or land use. So there is a lack of typology research on the overall performance of the metro station areas. To reach the general objective, 5 sub-objectives were proposed for this study: to define the TOD concept in the context of Beijing; to identify existing methods to evaluate TOD; to extract indicators for describing the metro station areas in Beijing; to develop an overview of existing methods for TOD typology; and to develop a TOD typology suited to the context of Beijing.

To reach the first sub-objective, numerous studies were reviewed to know about the TOD concept, and the successful implementation of TOD policy or application. Then, by reviewing the documents related to Beijing (e.g., the master plan of Beijing, Guidelines) to understand what are the relevant planning aspects of TOD in Beijing. At a city level, rail network planning and optimal utilization of urban land are required, following the needs of urban development strategies and combined with the city's spatial structure and functional zone. Because the metro planning and land use planning in Beijing are two separate processes, the metro transit system was built after urban development. The goal of the station areas is to integrate the station with the surrounding area, establish a safe, convenient and comfortable transit environment, and improve the quality of urban public space, rather than blindly pursuing high density.

The second objective was also achieved by a literature review. An extended review of research focusing on measuring and evaluating TOD has been conducted. Based on the formulated dimensions and indicators suited for the study area, an aggregated TOD index can be calculated by using multicriteria, PCA (principal component analysis) or expert scoring, to measure or evaluate the real situation. However, such an aggregated value cannot describe the performance of the station area more accurately. Therefore, a TOD typology was developed to analyze the Beijing metro station areas, which can better show the characteristics of different station areas and have similar planning methods for them with the same characteristics.

Through interviews with the experts from the government, namely researchers from urban design and transportation planning, a better understanding of the Beijing context, and herewith the third objective was achieved. A list of commonly used indicators was formed from abundant related research. The addition of new indicators was allowed (e.g. the effective width of the cycle lane and sidewalk), experts were required to score each indicator and dimension according to the importance of the perspectives of their study or working fields. Finally, the available data were combined to form an indicator list suitable for TOD measurement in Beijing. The node function measures the proximity to the city centre (N1), number of exits (N2), number of metro stations can be reached within 20 minutes (N3), distance from the exit to the nearest store (N4), and number of served directions by metro (N5). The place function includes 4 sub-dimensions, *bus connection*, *facilities*, *density* and *diversity*. The indicators are number of connected bus stops (C1), number of served bust lines (C2), distance from the exit to the nearest store (C3), number of the parking lot (F1), effective width of cycle lane (F2), effective width of the sidewalk (F3), number of intersections with signals (F4), population density (D1), road density (D2), number of catering, stores and hotels (S1), number of scientific, educational, cultural and health organizations (S2), number of government agencies (S3), and land use mixed (S4).

The fourth objective was to review the existing methods used for TOD typology. Different from the normative classification methods that only outline the characteristics, the positive methods provide the typology based on the measuring or evaluating the existing situation, such as the node-place model, it measures the accessibility of the station and the diversity of the activities within a station area, and reflects the relationship between the two aspects. In the initial operation, the indicators were converted into two indices by multicriteria analysis. In later applications, analysis methods such as K-means, hierarchical cluster analysis, latent class model were used in classification research. Some scholars modified the node-place model by adding a new axis to measure TOD.

Supported by the theory of the land use-transport feedback cycle, the classic node-place model was used to identify the TOD typology for metro station areas in Beijing. Based on the formed indicators and scores given by experts, a node index and a place index were calculated and displayed in a diagram. What's more, a sunburst was selected to visualize the indicators for each dimension, which is seen as a good way to visualize the hierarchical data.

First, the node-place model was applied to the data set in 2020, according to their positions located in the model, 5 classes were identified. The stressed station areas are those areas of transfer stations within the central city zone, both the node function and place function reach the highest level. Especially for the station areas within the CBD. The other transfer stations also have high node values, and are much higher than the place function, especially for the station areas located within the historical zone, which are seen as unsustained nodes. Due to the need to protect historical sites, the land does not allow excessive development, so the place value is not very high, but the facilities or infrastructures within the areas are complete. The balanced station areas are those areas which are not very close to the city centre, and there are no other metro lines connected to them. The accessibility of metro and the diversity of the social activities have reached a relative balance and are at a medium level. Unsustained places are those station areas within the central city zone with a high degree of land development and are rich in resources and activities. Because they are not the transfer station, the node value is at a moderate level. Other unsustained places occur in the station areas located in the sub-centre area. Because they are close to the terminal and far from the city centre, the accessibility is relatively very low. The main reason for relatively high place value is the high quality of cycle lane and sidewalk. Station areas with low values in both two aspects are divided into "dependence".

Then, the data set in 2015 was added into the model to see how the station areas changed over time. Generally, most of them are moving towards a balanced development. Upgrading is a more likely balancing measure than downgrading, and there is a trend from low to high along the diagonal (dependence-balance-stress). The increasing node value can be explained by the newly opened stations and connected metro lines. The change in the place value may be caused by population migration, road construction, demolition of illegal construction, an increase of service facilities, etc. An interesting finding is that there are several station areas with a deviating development. For the station areas within the historical zone, it is required to reduce population and demolish illegal buildings and low-end businesses, to achieve the goal of protecting historical sites and improving living quality. Therefore, the place values of these areas decrease. Due to the increased node function, they are moving towards unsustained nodes. For some station areas on the other side of the diagonal line, there is a significant improvement in the place function. Because the node function has not changed much, they tend to move to the unsustained place. In the planning, these stations will be connected with new metro lines, so the node function will also increase in the future.

LIST OF REFERENCE

Alarcón, F., Cho, Y. J. J., Degerstrom, A., Hartle, A., & Sherlock, R. (2018). *The TOD Evaluationg Method Evaluating TOD on Station Area and Corridor Scales*. Retrieved October 19, 2019, from the University of Minnesota Digital Conservancy, http://hdl.handle.net/11299/208305.

Atkinson-Palombo, C., & Kuby, M. J. (2011). The geography of advance transit-oriented development in metropolitan Phoenix, Arizona, 2000–2007. *Journal of Transport Geography*, *19*(2), 189–199. https://doi.org/10.1016/j.jtrangeo.2010.03.014

Beijing Municipal Commission of Planning and Natural Resources. (2017). *Beijing Urban Master Plan (2016-2035).* Retrieved October 29, 2019, from http://ghzrzyw.beijing.gov.cn/zhengwuxinxi/zxzt/bjcsztgh20162035/202001/t20200102_1554613.html

Beijing Municipal Commission of Planning and Nature Resources. (2014). *Code for planning & design on urban road space*. Beijing.

Beijing Transport Institute. (2019). *2019 Beijing Transport Annual Report*. Retrieved January 29, 2020, from http://www.doc88.com/p-2061695957458.html

Belzer, D., & Autler, G. (2002). *Transit-oriented development: Moving from rhetoric to reality*. Washington, DC: Brookings Institution Center on Urban and Metropolitan Policy.

Bertolini, L. (1999). Spatial development patterns and public transport: The application of an analytical model in the Netherlands. *Planning Practice and Research*, *14*(2), 199–210. https://doi.org/10.1080/02697459915724

Bertolini, L., & Spit, T. (1998). *Cities on rails : the redevelopment of railway station areas*. London; New York: E & FN Spon.

Black, D., & Henderson, V. (1999). A Theory of Urban Growth. *Journal of Political Economy*, *107*(2), 252–284. https://doi.org/10.1086/250060

Bruinsma, F., Pels, E., Priemus, H., Rietveld, P., & Van Wee, B. (2008). *Railway development: Impacts on urban dynamics*. *Railway Development: Impacts on Urban Dynamics*. Physica-Verlag. https://doi.org/10.1007/978-3-7908-1972-4

Cai, Z., & Zhang, Q. (2017). Grading of Urban Rail Transit Stations in Tianjin. *Create Living*, *6*, 69–70.

Calthorpe, P., & Poticha, S. (1993). *The Next American Metropolis: Ecology, Community, and the Ametrican Dream*. New York: Princeton Architectural Press.

Caset, F. (2019). *Planning for nodes, places, and people: a strategic railway station development tool for Flanders* (published doctoral dissertation, Ghent University). Retrieved April 13, 2020, from https://biblio.ugent.be/publication/8637955/file/8637956.pdf

Caset, F., Teixeira, F. M., Derudder, B., Boussauw, K., & Witlox, F. (2019). Planning for nodes, places and people in Flanders and Brussels: Developing an empirical railway station assessment model for strategic decision-making. *Journal of Transport and Land Use*, *12*(1), 811–837. https://doi.org/10.5198/jtlu.2019.1483

Cervero, R. (1998). *The transit metropolis : a global inquiry*. Island Press, Washington, DC.

Cervero, R., & Kockelman, K. (1997). Travel demand and the 3Ds: Density, diversity, and design. *Transportation Research Part D: Transport and Environment*, *2*(3), 199–219. https://doi.org/10.1016/S1361-9209(97)00009-6

Dittmar, H., & Ohland, G. (2004). *The new transit town : best practices in transit-oriented development*. Island Press.

Duan, D., & Zhang, F. (2013). Study on Classification of Urban Rail Transit Stations From the Perspective of Land Use Optimization : a Case Study on Xi ' an Subway Line 2. *City Planning Review*, *37*(9), 39–45.

Ewing, R., & Cervero, R. (2010). Travel and the Built Environment. *Journal of the American Planning Association*, *76*(3), 265–294. https://doi.org/10.1080/01944361003766766

Feudo, F. Lo. (2014). How to Build an Alternative to Sprawl and Auto-centric Development Model through a TOD Scenario for the North-Pas-de-Calais Region? Lessons from an Integrated Transportation-land Use Modelling. *Transportation Research Procedia*, *4*, 154–177. https://doi.org/10.1016/J.TRPRO.2014.11.013

Galelo, A., Ribeiro, A., & Martinez, L. . (2014). Measuring and Evaluating the Impacts of TOD Measures – Searching for Evidence of TOD Characteristics in Azambuja Train Line. *Procedia - Social and*

Behavioral Sciences, *111*, 899–908.
Groenendijk, L., Rezaei, J., & Correia, G. (2018). Incorporating the travellers' experience value in assessing the quality of transit nodes: A Rotterdam case study. *Case Studies on Transport Policy*, *6*(4), 564–576. https://doi.org/10.1016/j.cstp.2018.07.007
Hancock, M. M. B., Shepherd, D. S., Faatz, D. J., Lopez, D. P. D., Lehmann, D. P., Burns, A., … Duffany, B. (2014). *Transit Oriented Development Strategic Plan*. City of Denver.
Hanson, S., & Giuliano, G. (Eds.). (2004). *The Geography of urban transportation*. Guildford Press. New York.
He, F. (2018). *Evaluation method of the development in the metro station area based on TOD in Beijing*. (published master's thesis, Beijing University of Technology)
Higgins, C. D., & Kanaroglou, P. S. (2016). A latent class method for classifying and evaluating the performance of station area transit-oriented development in the Toronto region. *Journal of Transport Geography*, *52*, 61–72. https://doi.org/10.1016/J.JTRANGEO.2016.02.012
Hou, Q., & Li, S. (2011). Transport infrastructure development and changing spatial accessibility in the Greater Pearl River Delta, China, 1990–2020. *Journal of Transport Geography*, *19*(6), 1350–1360. https://doi.org/10.1016/J.JTRANGEO.2011.07.003
Huang, R., Grigolon, A., Madureira, M., & Brussel, M. (2018). Measuring transit-oriented development (TOD) network complementarity based on tod node typology. *Journal of Transport and Land Use*, *11*(1), 304–324. https://doi.org/10.5198/jtlu.2018.1110
ITDP. (2013). *TOD Standard 2.0*. Retrieved February 11, 2020, from www.itdp.org
Jacobs, M. (2000). Multinodal Urban Structures: A comparative analysis and strategies for design. Delft University Press.
Kamruzzaman, M., Baker, D., Washington, S., & Turrell, G. (2014). Advance transit oriented development typology: case study in Brisbane, Australia. *Journal of Transport Geography*, *34*, 54–70. https://doi.org/10.1016/J.JTRANGEO.2013.11.002
Li, T., Shi, Y., & Fu, W. (2015). Evolving TOD Concept and Its Sinicization. *Urban Planning International*, *30*(3), 72–77. Retrieved from https://wenku.baidu.com/view/cc5779e1a417866fb94a8e0b.html
Liang, Y. (2018). China makes steady progress in urbanization. Retrieved October 19, 2019, from http://xinhuanet.com/english/2018-09/10/c_137458990.htm
Litman, T., & Laube, F. (2002). *Automobile Dependency and Economic Development*. Retrieved October 19, 2019, from www.istp.murdoch.edu.au
Liu, Q. (2019). TOD Planning Guidelines in China. *Urban Transport of China*, *17*(2), 75–83. https://doi.org/10.13813/j.cn11-5141/u.2019.0209
Lyu, G., Bertolini, L., & Pfeffer, K. (2016). Developing a TOD typology for Beijing metro station areas. *Journal of Transport Geography*, *55*, 40–50. https://doi.org/10.1016/j.jtrangeo.2016.07.002
Maidina, H., & Mu, R. (2018). Evaluation on integrated development of urban transport and land use. *Land Use*, *42*(7), 86–92.
Ministry of Housing and Urban-Rural Development of the People's Republic of China (MOHURD). (2015). *Guidelines for planning and design of areas along urban rail transit*. Retrieved October 11, 2019, from http://www.mohurd.gov.cn
Olaru, D., Moncrieff, S., McCarney, G., Sun, Y., Reed, T., Pattison, C., … Biermann, S. (2019). Place vs. Node transit: Planning policies revisited. *Sustainability (Switzerland)*, *11*(2). https://doi.org/10.3390/su11020477
Park, K., Ewing, R., Scheer, B. C., & Tian, G. (2018). The impacts of built environment characteristics of rail station areas on household travel behavior. *Cities*, *74*(January), 277–283. https://doi.org/10.1016/j.cities.2017.12.015
Peng, Z. R., Sun, J., & Lu, Q. C. (2012). China's public transportation: Problems, policies, and prospective of sustainability. *Journal of the Institute of Transportation Engineers*, *82*(5), 36–40.
Practice, P., Peek, G., Rotterdam, H., Bertolini, L., & Jonge, H. De. (2006). Gaining insight in the development potential of station areas : A decade of node- place modelling in The Netherlands Planning Practice and Research, (September 2015). https://doi.org/10.1080/02697450701296247
Reconnecting America, & the Center for Transit-Oriented Development. (2008). Station Area Planning: How to Make Great Transit-Oriented Places. *Oklan: Reconnecting America*.
Reusser, D. E., Loukopoulos, P., Stauffacher, M., & Scholz, R. W. (2008). Classifying railway stations for sustainable transitions – balancing node and place functions. *Journal of Transport Geography*, *16*(3), 191–202. https://doi.org/10.1016/J.JTRANGEO.2007.05.004

Rodrigue, J.-P., Comtois, C., & Slack, B. (2013). *The Geography of Transport Systems . The Geography of Transport Systems*. Routledge. Retrieved November 19, 2019, from https://people.hofstra.edu/geotrans/eng/ch5en/conc5en/logistic_costs_breakdown.html

Sanders, J. (2015). Linking station node- and place functions to traffic flow : a case study of the Tokyu Den-En Toshi line in Tokyo, Japan. Retrieved from https://essay.utwente.nl/67082/

Singh, Y. J., Fard, P., Zuidgeest, M., Brussel, M., & van Maarseveen, M. (2014). Measuring transit oriented development: A spatial multi criteria assessment approach for the City Region Arnhem and Nijmegen. *Journal of Transport Geography*, *35*, 130–143. https://doi.org/10.1016/j.jtrangeo.2014.01.014

Singh, Y. J., Lukman, A., Flacke, J., Zuidgeest, M., & Van Maarseveen, M. F. A. M. (2017). Measuring TOD around transit nodes - Towards TOD policy. *Transport Policy*, *56*, 96–111. https://doi.org/10.1016/j.tranpol.2017.03.013

Spence, M., Annez, P. C., & Buckley, R. M. (Eds.). (2008). *Urbanization and growth*. World Bank Publications.

Thomas, R., Pojani, D., Lenferink, S., Bertolini, L., Stead, D., & van der Krabben, E. (2018). Is transit-oriented development (TOD) an internationally transferable policy concept? *Regional Studies*, *52*(9), 1201–1213. https://doi.org/10.1080/00343404.2018.1428740

Tumlin, J., & Millard-Ball, A. (2003). How to make transit-oriented development work. *PLANNING-CHICAGO-*, *69*(5), 14-19.

United Nations. (2018). 2018 Revision of World Urbanization Prospects. Retrieved October 9, 2019, from https://www.un.org/development/desa/publications/2018-revision-of-world-urbanization-prospects.html

United Nations. (2019a). About the Sustainable Development Goals - United Nations Sustainable Development. Retrieved October 19, 2019, from https://www.un.org/sustainabledevelopment/sustainable-development-goals/

United Nations. (2019b). *The Sustainable Development Goals Report*. New York.

Vaessens, B. (2005). Synergie op stationslocaties. *Doctoraal scriptie Sociale Geografie, Faculteit Geowetenschappen, Afstudeerrichting Economische Geografie, Universiteit Utrecht, Utrecht*.

Vale, D. S., Viana, C. M., & Pereira, M. (2018). The extended node-place model at the local scale: Evaluating the integration of land use and transport for Lisbon's subway network. *Journal of Transport Geography*, *69*, 282–293. https://doi.org/10.1016/j.jtrangeo.2018.05.004

Van Vught, F. A., & Ziegele, F. (Eds.). (2012). *Multidimensional ranking: The design and development of U-Multirank* (Vol. 37). Springer Science & Business Media.

Wegener, M., & Fürst, F. (2004). Land-use transport interaction: state of the art. *Available at SSRN 1434678*.

Xu, W., Zheng, C., Ma, G., Li, R., & Pingxin, D. (2018). Urban Rail Transit Site Classification Based on k-means Clustering. *Journal of Guizhou University (Nature Sciences)*, *35*(6), 106–111.

Zemp, S., Stauffacher, M., Lang, D. J., & Scholz, R. W. (2011). Classifying railway stations for strategic transport and land use planning: Context matters! *Journal of Transport Geography*, *19*(4), 670–679. https://doi.org/10.1016/J.JTRANGEO.2010.08.008

Zhao, P., & Li, S. (2018). Suburbanization, land use of TOD and lifestyle mobility in the suburbs: An examination of passengers' choice to live, shop and entertain in the metro station areas of Beijing. *Journal of Transport and Land Use*, *11*(1), 195–215. https://doi.org/10.5198/jtlu.2018.1099

Zhou, H. (2018). *Research on Spatial Performance Evaluation Index System of Urban Rail Transit Center Station Adjacent Area*. (published master's thesis, Southwest Jiaotong University).

Zhou, Q., & Dai, D. (2017). The evaluation of transit oriented development of metro station areas using node place index in Shenzhen China. In *inaugural World Transport Convention. Beijing, China*.

Zhu, Z., Li, Z., Liu, Y., Chen, H., & Zeng, J. (2017). The impact of urban characteristics and residents' income on commuting in China. *Transportation Research Part D: Transport and Environment*, *57*, 474–483. https://doi.org/10.1016/j.trd.2017.09.015

APPENDIX 1 INTERVIEW MATERIAL

UNIVERSITY OF TWENTE.

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Dear experts, my name is Yu Li. I am currently studying at ITC in the Netherlands, specializing in urban planning and management. First of all, thank you very much for taking time out of your busy schedule to read the material and for participating in my interview. Second, I will briefly explain the research significance, content, and objectives of this interview. Then comes my personal background. Finally are the detailed interview questions.

1. Thesis topic

Topic: A Contextual Transit-oriented Development Typology of Beijing Metro Station Areas

Significance:

1.TOD

TOD is Transit-oriented Development. It encourages the development along the transit lines or around the stations, provides jobs, reduces commuting time, reduces the distance or time for achieving social activities, improves the accessibility, and establishes a friendly environment of walking and cycling to achieve the goals of green travel and sustainable development.

2. Social problem

There is no clear document for classification of the Beijing metro station areas. Except for the classification based on the characteristics of the stations' construction, or sorting based on passenger flow, and the single dimension such as land use, it lacks a reasonable classification method. This study **focuses on the entire built environment, including the metro stations and their surrounding areas.**

Eg, station Gongzhufen is not a friendly used station. It has to walk over 300m to the nearest bus stop.

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Main objective	Sub-objective	Question	Method
To develop a TOD typology for Beijing metro station areas.	1. To define the TOD concept in the context of Beijing.	1) What are the relevant planning objectives for TOD in the context of Beijing? 2) What are the important contextual local station area transport planning aspects? 3) Which of these are relevant for TOD in Beijing?	Literature review Expert interview
	3. To extract indicators to describe the metro station areas in Beijing from literature and local experts.	1) What is the size of a TOD area in the context of Beijing? 2) Which features are important for describing the station and its surrounding area? 3) What are the relevant qualitative indicators? 4) What are the relevant quantitative indicators?	Literature review Expert interview Data collection

Interview objective:

1.Understand different policy backgrounds in the field of urban planning, architectural, construction, commercial and transportation planning, and the common goals related to this study.

2. Factors affecting the development of TOD in Beijing from different angles.

3. Sort the given factors by importance.

4. Add factors that have not been considered.

5. Make comments or suggestions on the line selection, the catchment size and other information relevant to this stud.

6. The content and the information of interviewees will be kept confidential according to the interviewees' requirements.

2. Author information

Name: Yu Li

College: Faculty of Geo-information Science and Earth Observation (ITC)

Specialization: Urban Planning and Management (UPM)

E-mail: y.li-10@student.utwente.nl

Place: **Date:** **Interviewee:**

The content and the information of interviewees will be kept confidential according to the interviewees' requirements. Interview duration is about 30-60 minutes.

3. Interview questions

1. The working experience in the field related to TOD.

- Background

- Objective

- Related policy (eg, Beijing master plan, Guidelines for planning and design of areas along urban rail lines……)

2. The classification of metro station areas (eg, passenger volume, platform construction……).

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3. Factors and ranking (The factors listed in the table are for reference only and are not ranked in any order.)

Dimension	Sub-dimension	factor	Ranking
Station		Design of the platform and station	
		Service level	
		Number of staff	
		Number of connection track lines	
		Passenger volume	
		Distance to the city centre	
		Entrances/exits	
		Accessibility	
Surrounding area	Interchange facilities	Number of connection methods	
		Number of each connection method	
		Distance to the nearest bus stop	
		Parking lot	
	Transport facilities	Sidewalk facilities	
		Bicycle lane facilities	
		Intersection	
	Density	Population density	
		Job density	
		Road density	
	Diversity	The area of green space, square and park.	
		Mixed land use	
	Environment		
Passengers' experience		Satisfaction	

4. Comment and suggestion

4.1 The size of the catchment

4.2 Line selection

4.3 Other information

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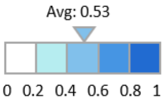
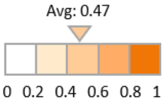
APPENDIX 2 SUNBURST CHART

ID	Visualization in 2015	Visualization in 2020

Legend:





Node – Accessibility
N1 Proximity to the city centre
N2 Number of entrances/exits
N3 Number of metro stations can be reached within 20 min
N4 Distance from the exit to the nearest store
N5 Number of served directions by metro

Place – Bus connection
C1 Number of connected bus stops
C2 Number of served bus lines
C3 Distance from the exit to the nearest store

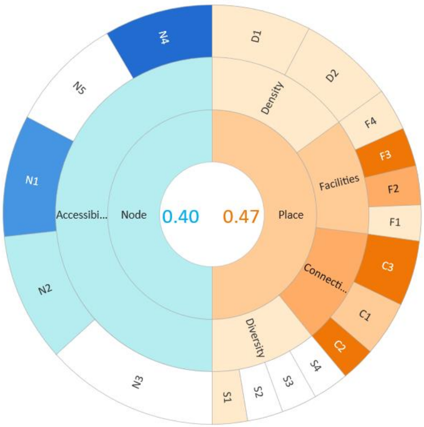
Place – Facilities
F1 Number of parking lot
F2 Effective width of cycle lane
F3 Effective width of sidewalk
F4 Number of intersections with signals

Place – Density
D1 Population density
D2 Road density

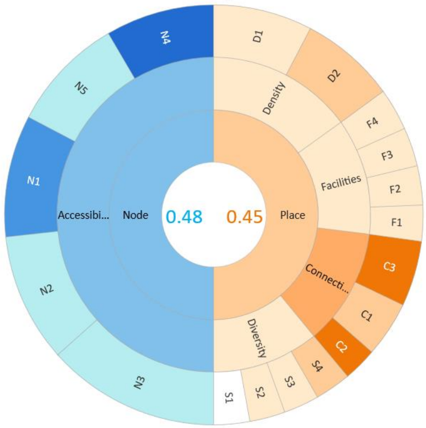
Place – Diversity
S1 Commercial stores
S2 Public services
S3 Government agencies
S4 Land use mixed

1

Indicators of Haidian Wuluju Station Area in 2015

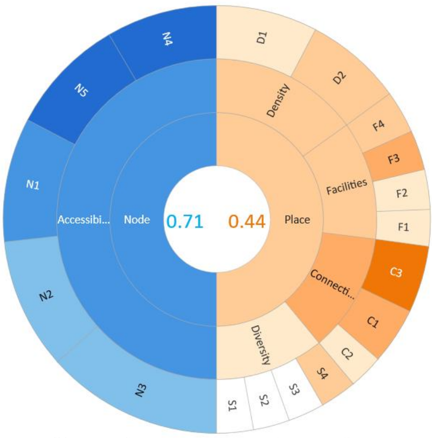


Indicators of Haidian Wuluju Station Area in 2020

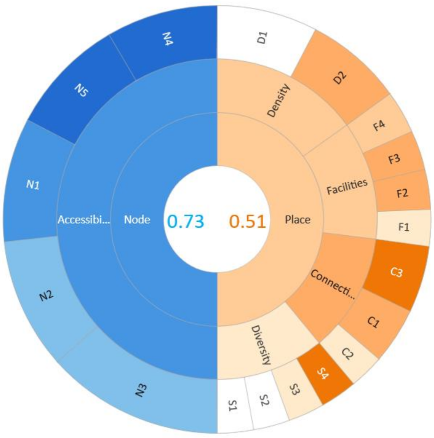


2

Indicators of Cishou Si Station Area in 2015

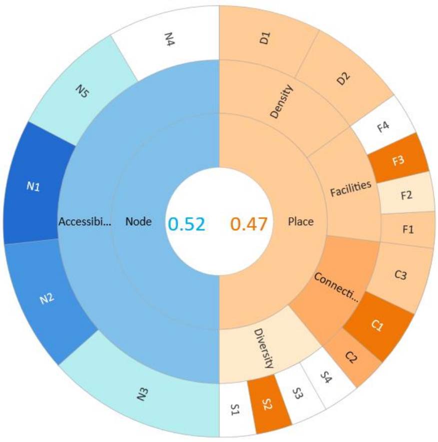


Indicators of Cishou Si Station Area in 2020

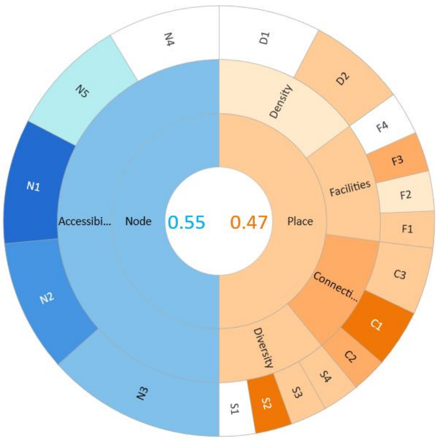


3

Indicators of Huayuan Qiao Station Area in 2015

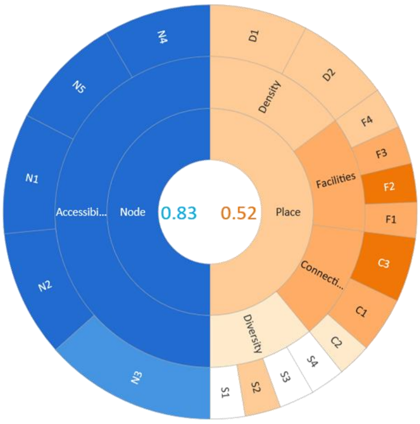


Indicators of Huayuan Qiao Station Area in 2020

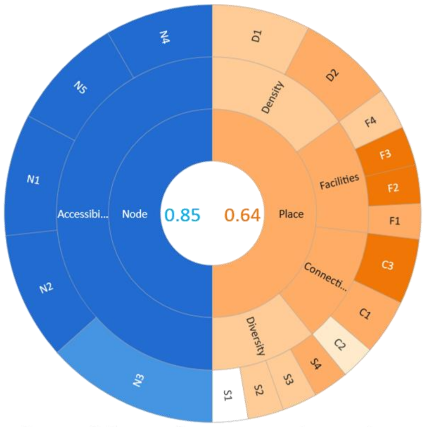


4

Indicators of Baishi Qiao South Station Area in 2015

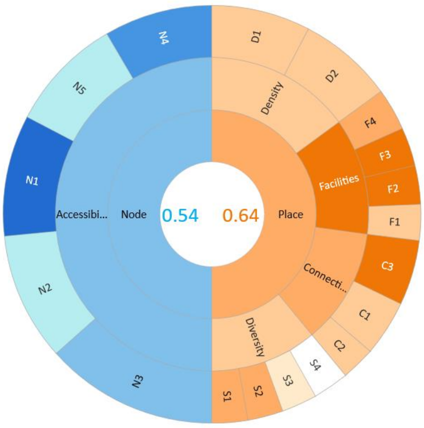


Indicators of Baishi Qiao South Station Area in 2020

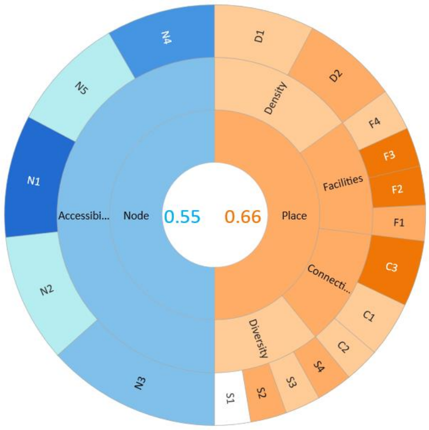


5

Indicators of Chegong Zhuang West Station Area in 2015

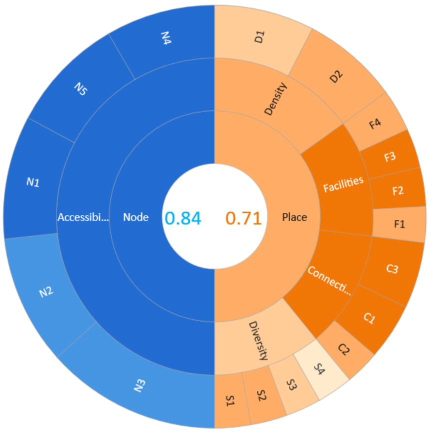


Indicators of Chegong Zhuang West Station Area in 2020

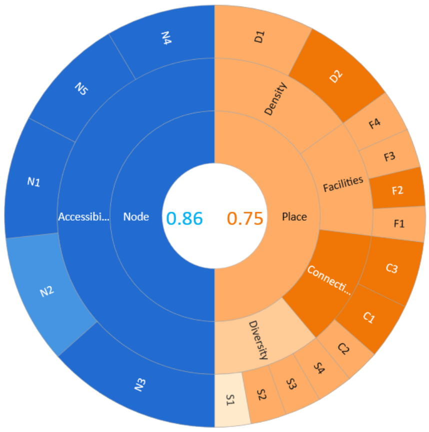


6

Indicators of Chegong Zhuang Station Area in 2015

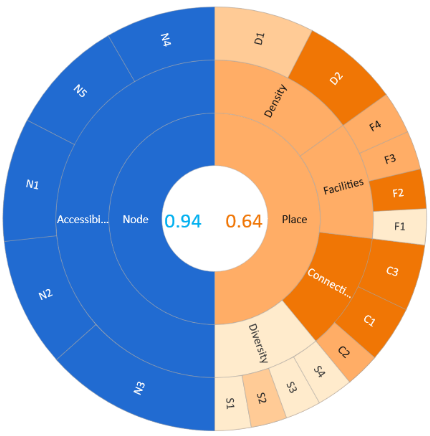


Indicators of Chegong Zhuang Station Area in 2020

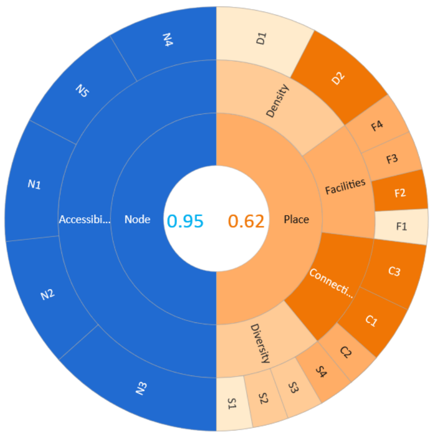


7

Indicators of Ping' an Li Station Area in 2015

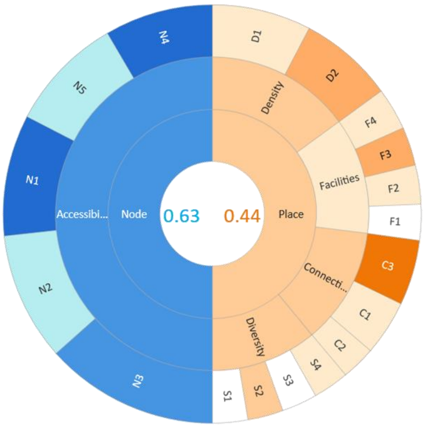


Indicators of Ping' an Li Station Area in 2020

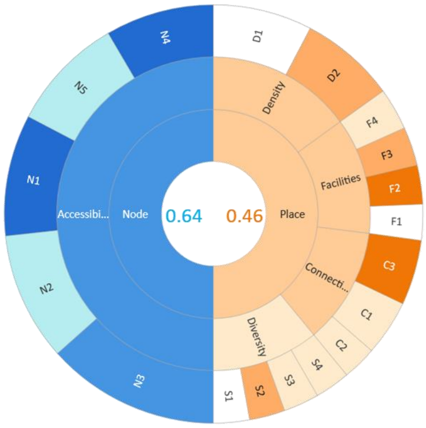


8

Indicators of Beihai North Station Area in 2015

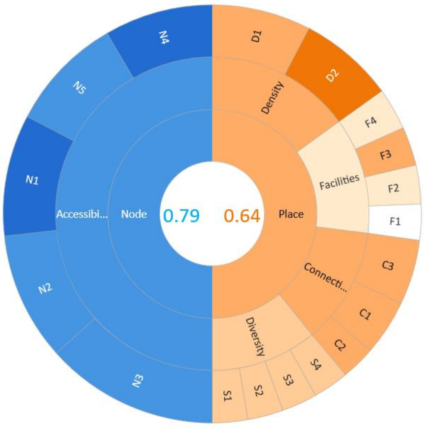


Indicators of Beihai North Station Area in 2020

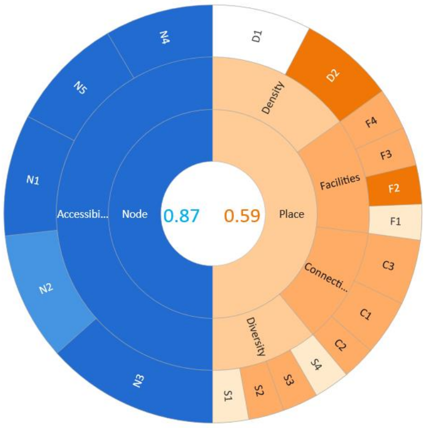


9

Indicators of South Luogu Lane Station Area in 2015

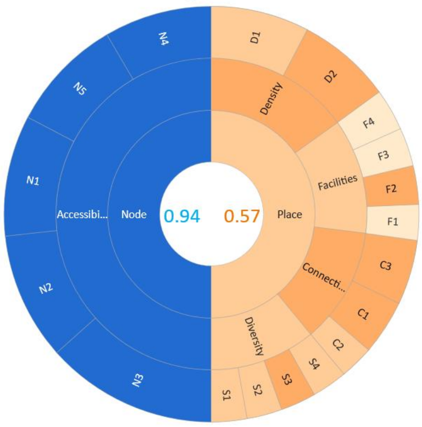


Indicators of South Luogu Lane Station Area in 2020

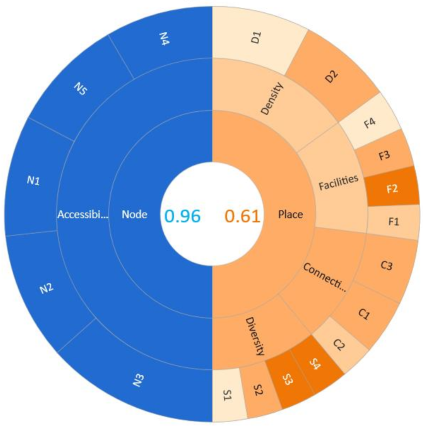


10

Indicators of Dong Si Station Area in 2015

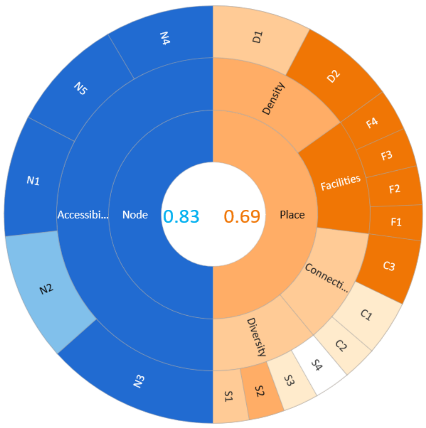


Indicators of Dong Si Station Area in 2020

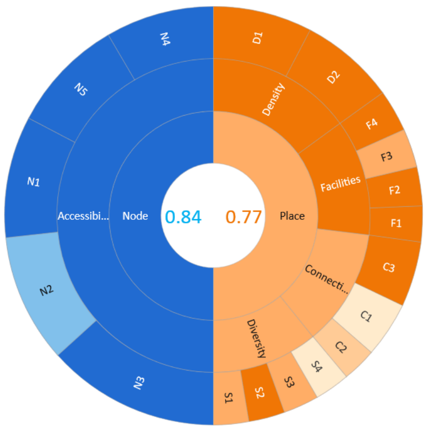


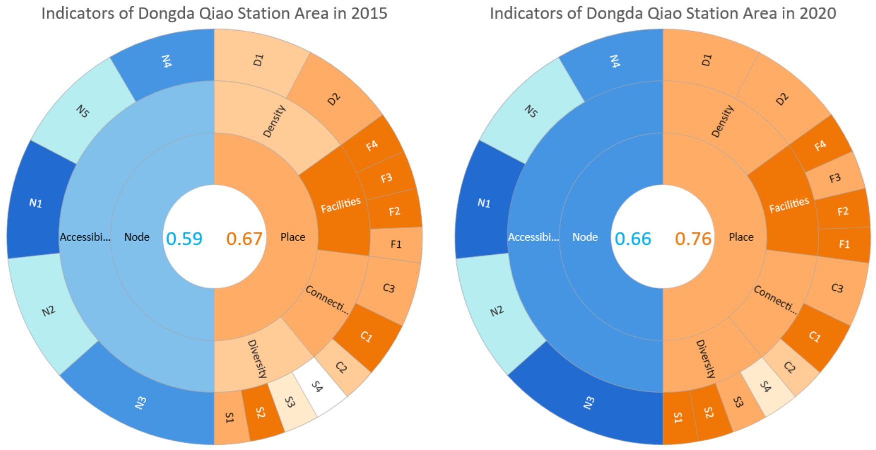
11

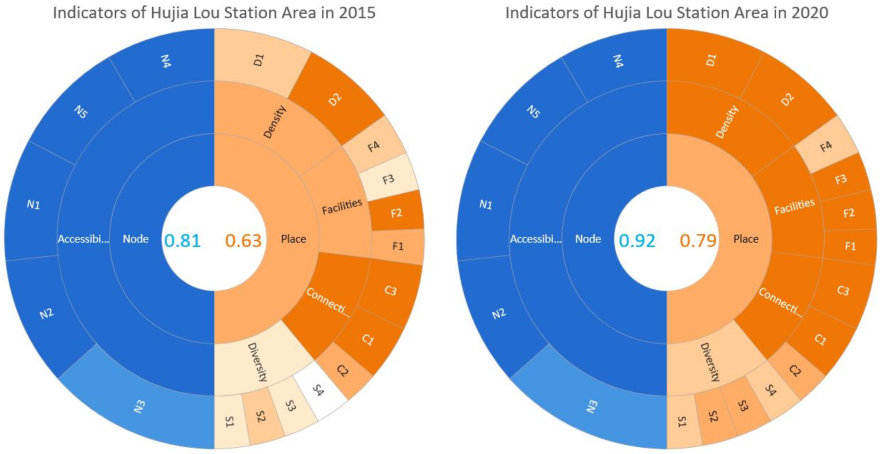
Indicators of Chaoyang Men Station Area in 2015

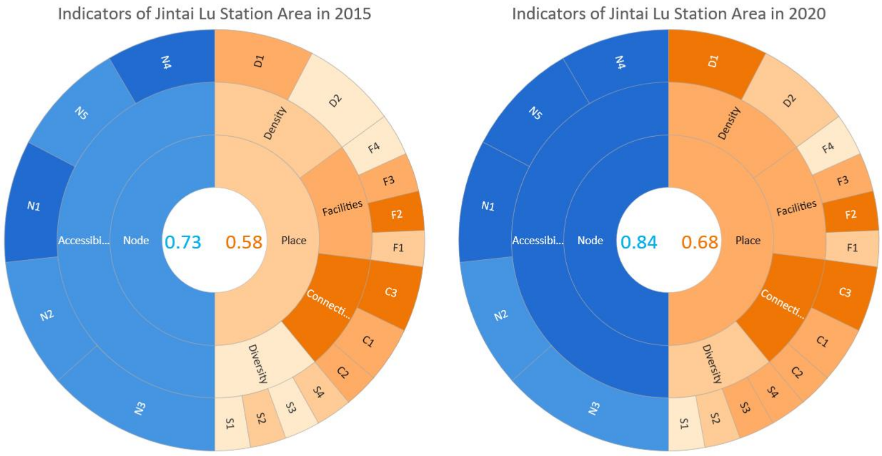


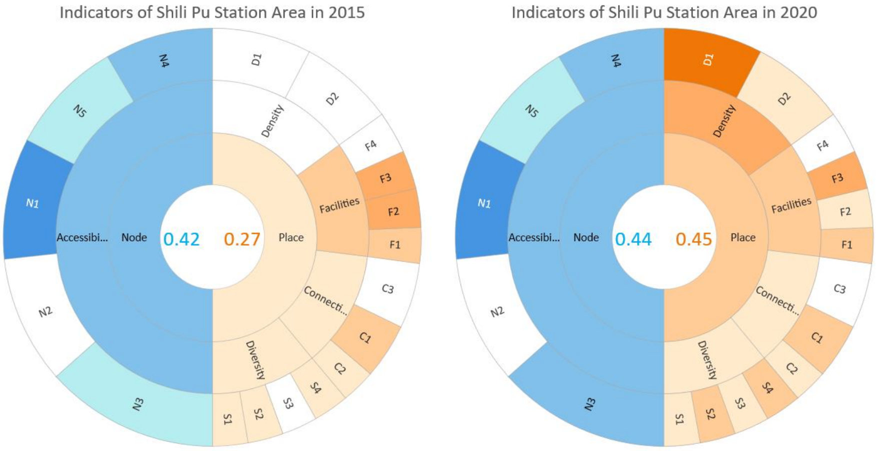
Indicators of Chaoyang Men Station Area in 2020



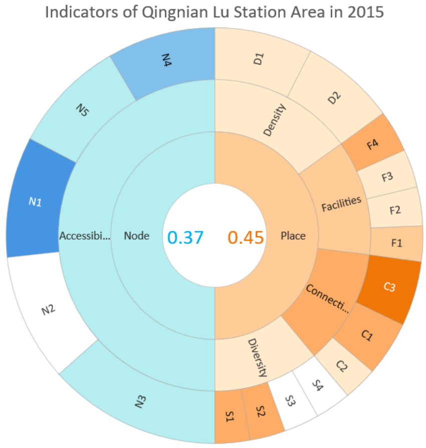
12

Indicators of Dongda Qiao Station Area in 2015
0.59
0.67
Indicators of Dongda Qiao Station Area in 2020
0.66
0.76

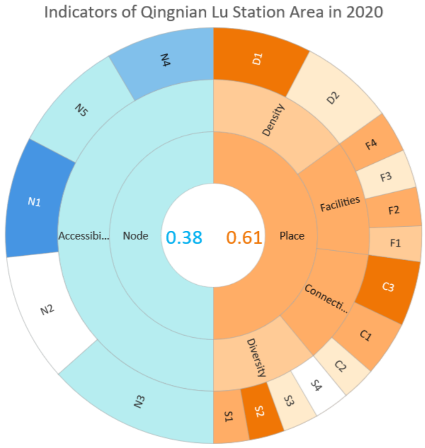
13

Indicators of Hujia Lou Station Area in 2015
0.81
0.63
Indicators of Hujia Lou Station Area in 2020
0.92
0.79

14

Indicators of Jintai Lu Station Area in 2015
0.73
0.58
Indicators of Jintai Lu Station Area in 2020
0.84
0.68

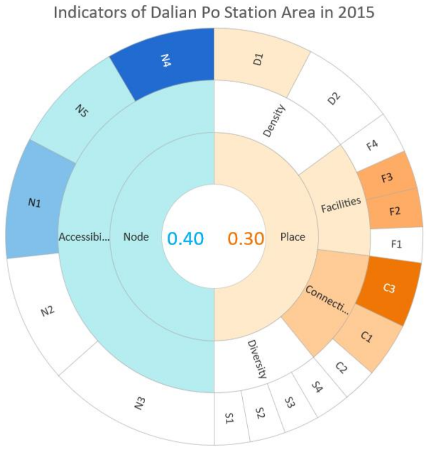
15

Indicators of Shili Pu Station Area in 2015
0.42
0.27
Indicators of Shili Pu Station Area in 2020
0.44
0.45

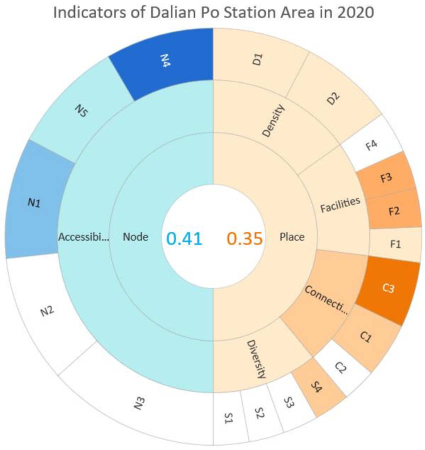
16


Indicators of Qingnian Lu Station Area in 2015
0.37
0.45
Node
Place
Accessibi...
Density
Facilities
Connecti...
Diversity
D1
D2
F4
F3
F2
F1
C3
C1
C2
S4
S3
S2
S1
N3
N2
N1
N5
N4

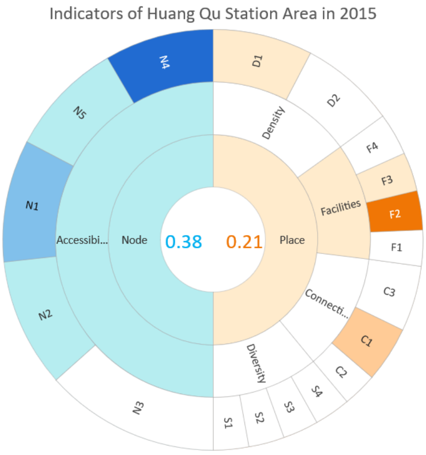

Indicators of Qingnian Lu Station Area in 2020
0.38
0.61
Node
Place
Accessibi...
Density
Facilities
Connecti...
Diversity
D1
D2
F4
F3
F2
F1
C3
C1
C2
S4
S3
S2
S1
N3
N2
N1
N5
N4

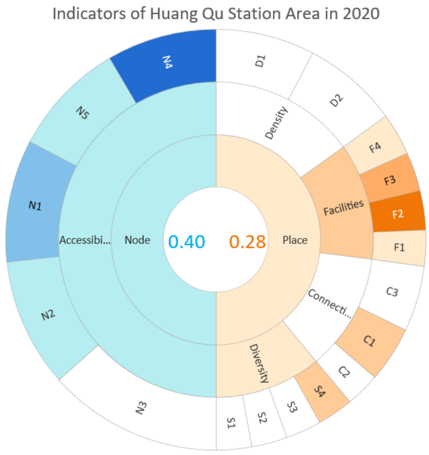
17


Indicators of Dalian Po Station Area in 2015
0.40
0.30
Node
Place
Accessibi...
Density
Facilities
Connecti...
Diversity
D1
D2
F4
F3
F2
F1
C3
C1
C2
S4
S3
S2
S1
N3
N2
N1
N5
N4

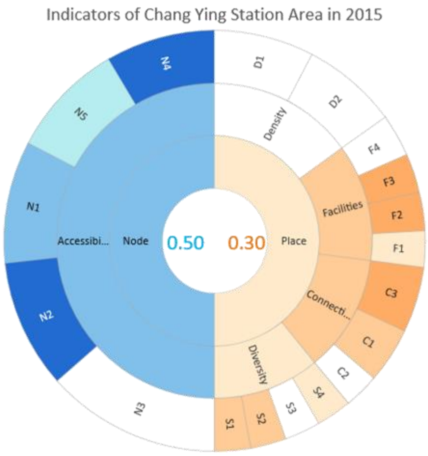

Indicators of Dalian Po Station Area in 2020
0.41
0.35
Node
Place
Accessibi...
Density
Facilities
Connecti...
Diversity
D1
D2
F4
F3
F2
F1
C3
C1
C2
S4
S3
S2
S1
N3
N2
N1
N5
N4

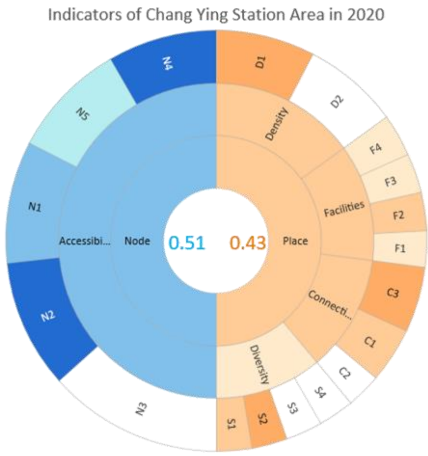
18


Indicators of Huang Qu Station Area in 2015
0.38
0.21
Node
Place
Accessibi...
Density
Facilities
Connecti...
Diversity
D1
D2
F4
F3
F2
F1
C3
C1
C2
S4
S3
S2
S1
N3
N2
N1
N5
N4


Indicators of Huang Qu Station Area in 2020
0.40
0.28
Node
Place
Accessibi...
Density
Facilities
Connecti...
Diversity
D1
D2
F4
F3
F2
F1
C3
C1
C2
S4
S3
S2
S1
N3
N2
N1
N5
N4

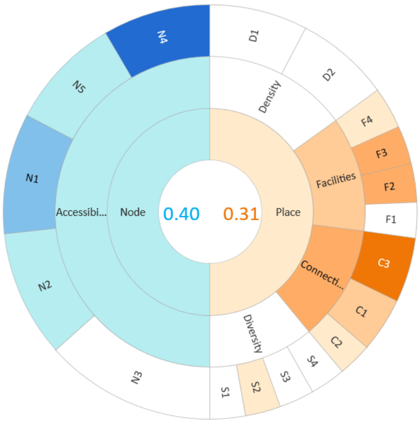
19


Indicators of Chang Ying Station Area in 2015
0.50
0.30
Node
Place
Accessibi...
Density
Facilities
Connecti...
Diversity
D1
D2
F4
F3
F2
F1
C3
C1
C2
S4
S3
S2
S1
N3
N2
N1
N5
N4

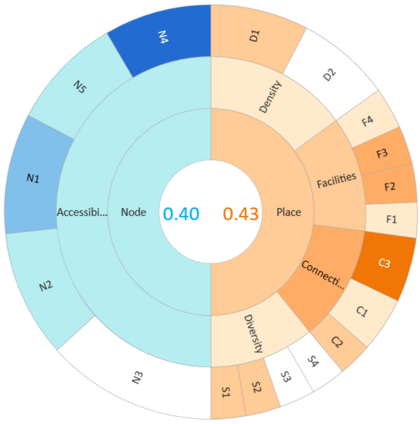

Indicators of Chang Ying Station Area in 2020
0.51
0.43
Node
Place
Accessibi...
Density
Facilities
Connecti...
Diversity
D1
D2
F4
F3
F2
F1
C3
C1
C2
S4
S3
S2
S1
N3
N2
N1
N5
N4

20

Indicators of Cao Fang Station Area in 2015

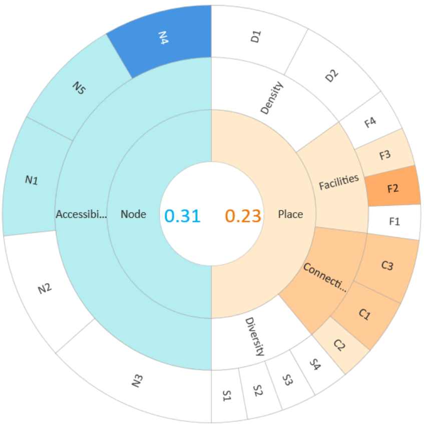


Indicators of Cao Fang Station Area in 2020

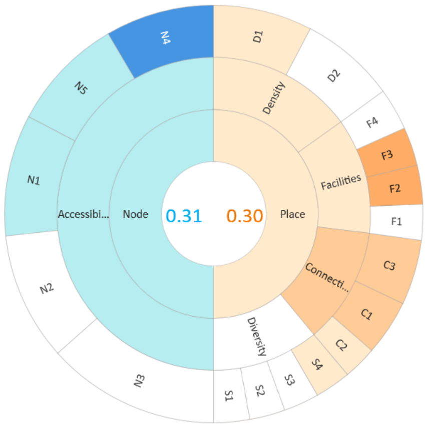


21

Indicators of Wuzixueyuan Lu Station Area in 2015

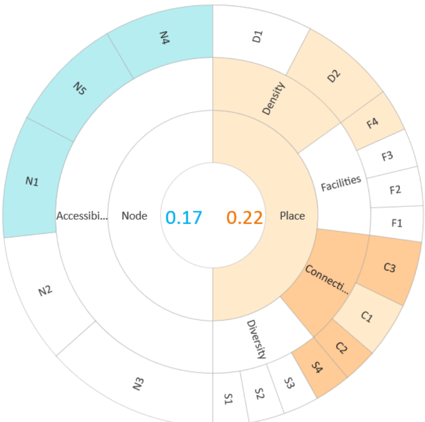


Indicators of Wuzixueyuan Lu Station Area in 2020

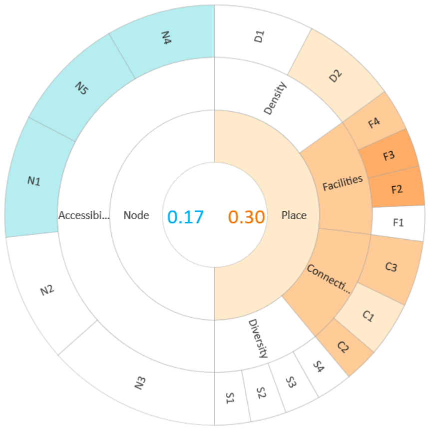


22

Indicators of Tongzhou Beiguan Station Area in 2015

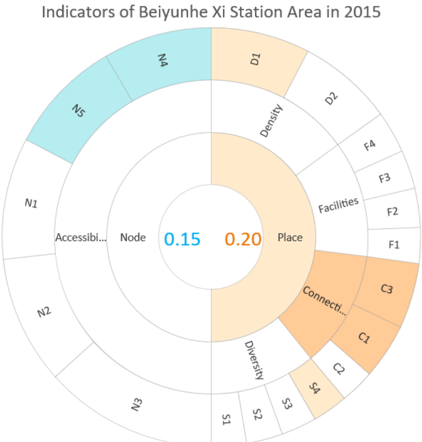


Indicators of Tongzhou Beiguan Station Area in 2020

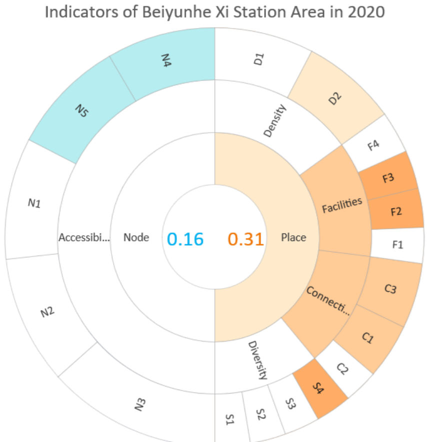


23

Indicators of Beiyunhe Xi Station Area in 2015

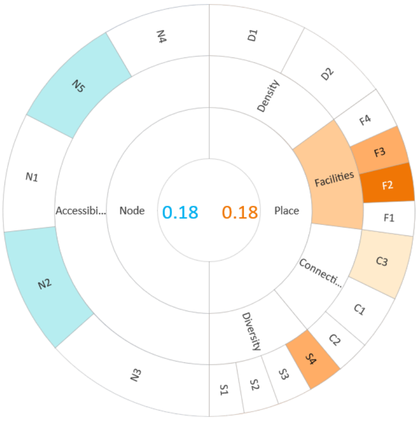


Indicators of Beiyunhe Xi Station Area in 2020

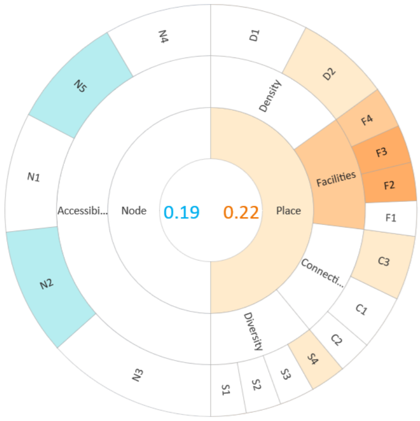


24

Indicators of Haojia Fu Station Area in 2015

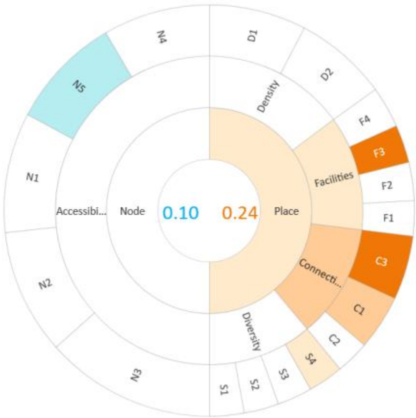


Indicators of Haojia Fu Station Area in 2020

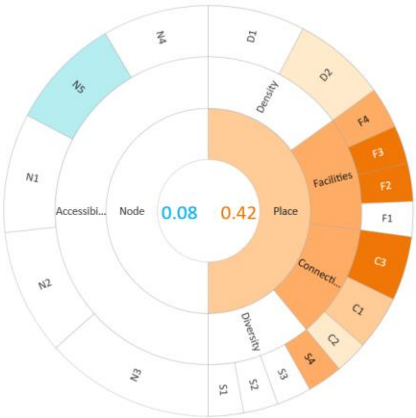


25

Indicators of Dongxia Yuan Station Area in 2015

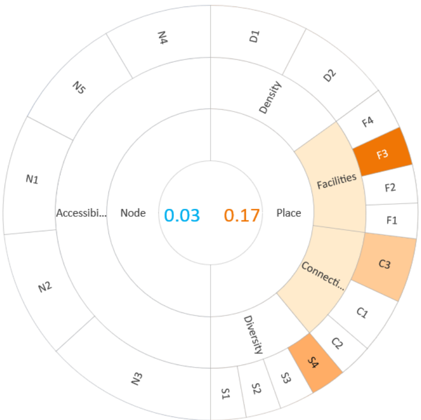


Indicators of Dongxia Yuan Station Area in 2020



26

Indicators of Lu Cheng Station Area in 2015



Indicators of Lu Cheng Station Area in 2020