land

MDPI

Article

Evaluation of Sustainable Development Potential of Railway Station Areas in Guangzhou Metropolitan Area: Based on the Extended "Node–Place–Support" Model

Jiawei Li [1], Zhongwei Shen [1,*], Jiexi Ma [1], Yangguang Hao [1], Rusi Zeng [2,3] and Ziqi Lin [1]

[1] School of Architecture, Southwest Jiaotong University, Chengdu 611756, China; jewel@my.swjtu.edu.cn (J.L.); mjx@my.swjtu.edu.cn (J.M.); hyg.swjtu.edu.cn@my.swjtu.edu.cn (Y.H.); linziqi@my.swjtu.edu.cn (Z.L.)
[2] College of Architecture and Environment, Sichuan University, Chengdu 610000, China; rusi_zeng@scu.edu.cn
[3] Institute of Urbanization Strategy and Architecture, Sichuan University, Chengdu 610000, China
* Correspondence: szwpaper@163.com

Abstract: As metropolitan regions expand, railway station areas (RSAs) encounter unprecedented challenges and opportunities regarding sustainability, influenced by transportation, location, and urban factors. However, there is currently a lack of models that assess the sustainable development status of RSAs from a macro perspective of regional integration. This study innovatively incorporates the dimension of city support into the traditional Node–Place (NP) model, constructing the "Node–Place–Support" (NPS) model. This model consists of three dimensions and 21 indicators, utilizing the entropy weight method and AHP methods to conduct a comprehensive assessment of the sustainable development levels of 12 RSAs within the Guangzhou metropolitan area. The results indicate that, compared to the traditional NP model, the NPS model effectively reveals the unique factors influencing the development of RSAs within the metropolitan area, emphasizing the collaborative importance of city support, transportation capacity, and station attractiveness. Furthermore, according to the new classification method of the NPS model, the 12 research samples can be categorized into four categories and seven subcategories. Lastly, optimization strategies should be tailored to the specific development status of RSAs and the characteristics of the city. This study presents a new paradigm for assessing and enhancing RSA sustainability, advocating for strategies tailored to local conditions.

Keywords: Node–Place model; railway station area; sustainable development; potential evaluation; metropolitan area

check for updates

Academic Editor: Bindong Sun

Received: 25 December 2024
Revised: 5 February 2025
Accepted: 8 February 2025
Published: 11 February 2025

Citation: Li, J.; Shen, Z.; Ma, J.; Hao, Y.; Zeng, R.; Lin, Z. Evaluation of Sustainable Development Potential of Railway Station Areas in Guangzhou Metropolitan Area: Based on the Extended "Node–Place–Support" Model. *Land* **2025**, *14*, 369. https://doi.org/10.3390/land14020369

Copyright: © 2025 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (https://creativecommons.org/licenses/by/4.0/).

1. Introduction

As a region characterized by a high concentration of non-agricultural industries, population, and various economic and social activities, the metropolitan area represents a significant and regular phenomenon in urban development, particularly evident in many cities of developed countries [1]. The Tokyo and London Metropolitan Areas, for instance, are notable for their efficient transit systems and economic vibrancy [2,3]. Within the context, the flow of resources between cities is accelerated, and the division of labor system becomes increasingly defined. The development of metropolitan areas not only facilitates the extension and expansion of rail transportation networks but also underscores the necessity and urgency for the construction and upgrading of railway station areas. China has launched a significant initiative known as the "integration of four networks", with the strategic objective of creating "metropolitan areas on the rail". This goal resonates

with the transportation planning and development strategies of other metropolitan areas internationally, highlighting the importance of railway station area (RSA) development for urban infrastructure [4].

The railway station area (RSA), as a strategic component of the metropolitan rail transportation network, serves the dual functions of guiding the flow of socio-economic factors and facilitating passenger traffic and transportation. To enhance the planning and design of RSAs and achieve sustainable development, scholars have crafted a range of quantifiable and comparative models and evaluation systems. The Space Syntax model, for example, is utilized to examine the spatial configuration and traffic patterns within railway station areas (RSAs) [5], while the Huff model forecasts commercial service demand and market potential around stations [6]. Additionally, the gravity model assesses the appeal and influence of stations [7].

In addition, the most commonly used evaluation model in the research is the Node–Place model (NP) and its variants, such as NPD, NPF, and NPN, have been applied globally to understand RSA patterns and interactions [8–12]. Through these international comparisons and studies, a more global perspective on the development of railway station areas in different metropolitan regions, along with policy recommendations, can be offered.

In the era of regional integration, the sustainable development of railway station areas (RSAs) in metropolitan regions is critical for new urbanization. Liao et al. (2020) [13] and Nian et al. (2019) [14] have contributed to construction option assessments and planning strategies for public transportation resilience. Zhao et al. (2024) [15] introduced an enhanced travel time model for RSA planning in the Xi'an metropolitan region. Researchers have also developed a comprehensive evaluation index system for RSAs, including factors such as transportation accessibility [16], development intensity [17], traffic organization [18], project development (Jacob Trip, 2008) [19], spatial structure [20], site location [21], and enterprise distribution [22]. Despite these efforts, a macro-level analysis of RSAs' role in transportation networks and urban development remains an underexplored area.

Upon synthesizing the aforementioned literature reviews, it becomes apparent that, while NP models have made significant contributions to evaluating the sustainability of RSAs, they are not without their shortcomings. The existing research emphasizes static analysis and falls short in capturing the dynamic interplay between urban development and RSAs from a macro perspective [23]. While some models strive to integrate various dimensions, the practical synthesis of economic, social, and environmental factors remains a formidable challenge. Moreover, the strategic positioning of RSAs within the larger metropolitan rail transit network and their functional carrying capacity are critical considerations [10]. Nonetheless, the macro-level role of RSAs in transportation networks and urban development has been notably underexplored. The diversity of NP models indeed illuminates the sustainable development of railroad station areas, yet the current research tends to overlook the influence of macro-contextual factors such as urban hierarchy and developmental positioning. The lack of a consensus on evaluation indicators, with an undue focus on transportation network perfection and land use diversity, further constrains the model's adaptability to novel contexts.

This study introduces an innovative approach to assess the sustainability of RSAs within the Guangzhou metropolitan region, examining 12 RSAs across four cities. We investigate the determinants of RSA sustainability, develop a NPS model based on the NP framework to quantify development levels, and propose tailored optimization strategies. This study aims to address three core questions: first, how are the factors affecting the development of RSAs in the context of metropolitan areas different from previous studies? Second, how to categorize the study sample based on the evaluation results? Third, what are the main aspects of sustainable development strategies for RSAs?

The paper is structured as follows: Section 2 describes the study area, research methodology, and data sources. In Section 3, the study demonstrates the specific application of the evaluation model in empirical research and its results. Section 4 discusses the contributions and limitations of this study. Section 5 provides the research conclusions.

2. Materials and Methods

2.1. Research Design

2.1.1. Study Areas

Guangzhou metropolitan area is an important part of the Guangdong–Hong Kong–Macao Greater Bay Area. The development plan is centered on Guangzhou City, with the core areas of Guangzhou City and Foshan City leading the way and the central urban areas of Zhaoqing City and Qingyuan City as the development poles. Relying on the major transportation corridors, the overall development pattern of the metropolitan area is constructed as "one core, two poles, and four axes". There is the Beijing–Guangzhou High Speed Railway, Guiguang–Guangzhou High Speed Railway, Nan–Guangzhou High Speed Railway, Guangzhou–Foshan–Zhaoxing Intercity, Guangzhou–Qingyuan Intercity, and other rail transportation lines in the metropolitan area, and the transportation infrastructure is mature. Considering the factors such as opening time, line type, and completeness of data acquisition, this paper selects 12 railway station areas in the Guangzhou metropolitan area as the object of research and evaluation (Figure 1). The basic situation of each station area and the city where it is located is summarized in Table 1.

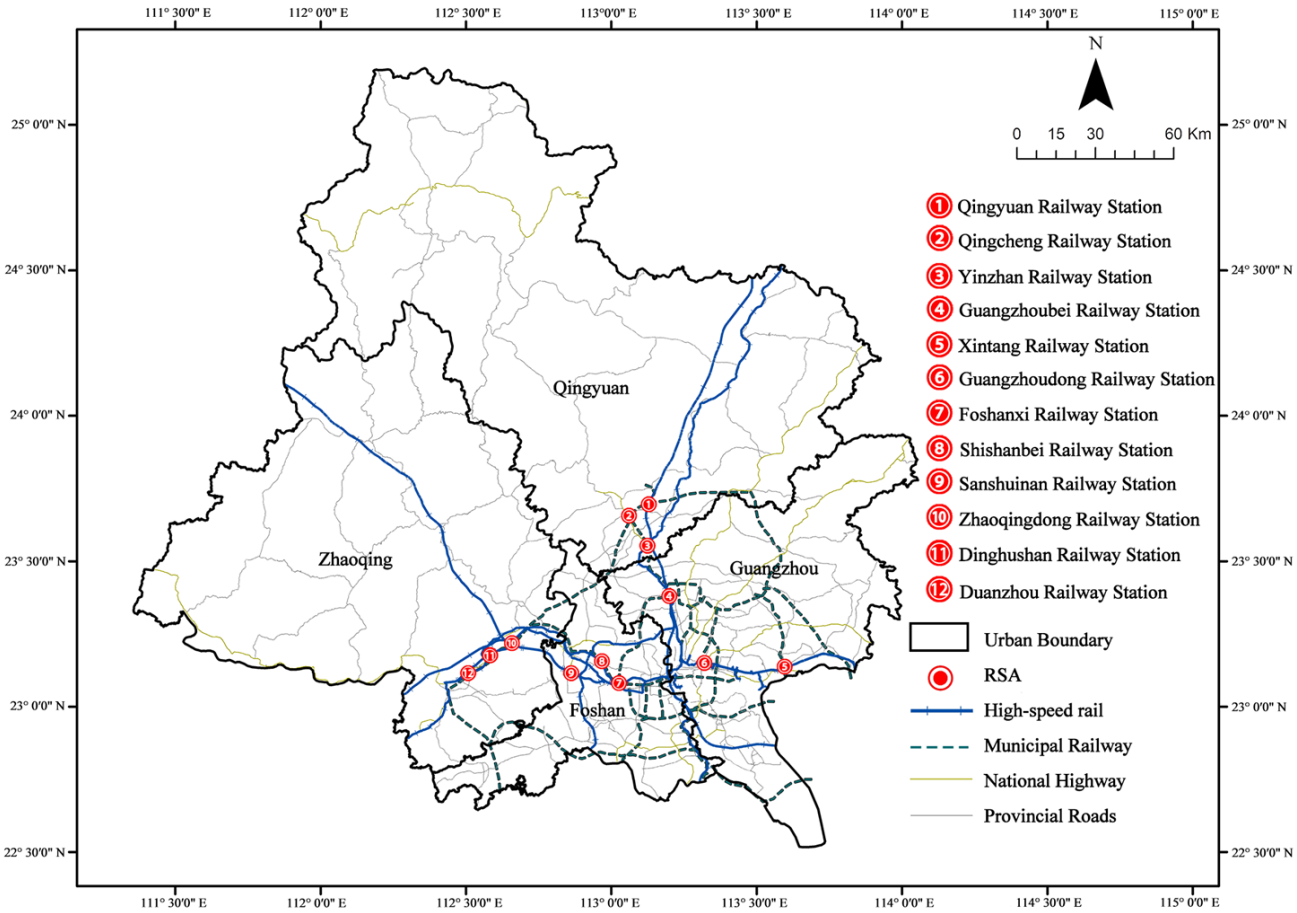


Figure 1. The 12 research samples in the Guangzhou metropolitan area.

Table 1. Basic information about the study site areas and the cities in which they are located.

Serial Number	City	GDP (Unit: 100 Million RMB)	RSA	Station Design Scale	Type of Route Opened to Traffic	Opening Time
1	Guangzhou	30355.73	Guangzhoudong Railway Station	7 stations and 14 lines	General speed railway, Intercity Railway	June 1996
2			Guangzhoubei Railway Station	8 stations and 16 lines	General speed railway, High-Speed Railway,	September 1999
3			Xintang Station	7 stations and 17 lines	High-Speed Railway, Intercity Railway	June 2015
4	Foshan	13276.14	Foshanxi Railway Station	10 stations and 23 lines	High-Speed Railway, Intercity Railway	August 2017
5			Sanshuinan Railway Station	3 stations and 8 lines	High-Speed Railway	December 2014
6			Shishanbei Railway Station	2 stations and 2 lines	Intercity Railway	March 2016
7	Qingyuan	2120.19	Qingyuan Railway Station	2 stations and 6 lines	High-Speed Railway	December 2009
8			Qingcheng Railway Station	2 stations and 4 lines	Intercity Railway	November 2020
9			Yinzhan Railway Station	2 stations and 2 lines	Intercity Railway	November 2020
10	Zhaoqing	2792.51	Zhaoqingdong Railway Station	5 stations and 14 lines	High-Speed Railway	January 2015
11			Duanzhou Railway Station	2 stations and 2 lines	Intercity Railway	March 2016
12			Dinghushan Railway Station	2 stations and 2 lines	Intercity Railway	March 2016

2.1.2. Delineation of the Research Scope of the RSAs

At present, different scholars have different understandings and delineation bases for the research scope of railway station areas, for example, the spatial structure around a high-speed railway station is divided into three circles, which are the core area (the area with a radius of 800 m centered on a high-speed railway station), the expanding functional area (the area with a distance of 800–2000 m), and the peripheral influence area (the area with a distance of 2000 m) [24]. Hugo proposed that the range area where the HSR station can be reached in 5–10 min on foot is the first circle, the range area where the HSR station can be reached in 10–15 min through the use of multiple modes of transportation is the second circle, and the range area where the HSR station can be reached in more than 15 min through the use of multiple modes of transportation is the third circle [25].

Considering factors such as the timing of the construction of the metropolitan area rail transit network and the development status of the surrounding areas, this study argues that the evaluation should include as large an area as possible in order to make considerations for the future development of the metropolitan area. Therefore, this study adopts a circular area with a 2-km radius centered on the station as the study area of the railway station area.

2.2. Methods

2.2.1. A New Perspective on the Assessment of Regional Development of Railway Stations: Integrated Consideration of Macroeconomic and Spatial Structural Factors

When assessing the level of regional development of a railway station, traditional NP models are often limited to the station and its surrounding local space. In the context of metropolitan area expansion, more macroscopic influencing factors should be considered. It has been clearly pointed out that the expansion and development of station areas are closely related to the socio-economic background and location conditions in which they are located [26]. In order to assess railway station areas from a more macro perspective,

we need to consider the level of urban development and overall spatial characteristics in an integrated manner. This approach helps us to understand the degree of sustainable development support that different cities can provide to the railway station area within the metropolitan area. The level of urban development is a comprehensive concept that is influenced by a combination of factors. Deng et al. (2019) found that the higher the overall economic development level of the city where the station is located, the higher the city class ranking, and the better the station's location conditions, the wider the development scope around the station usually is, and the faster the development speed is [27]. This finding not only verifies the importance of macro factors in the development of station areas but also provides new directions and ideas for our research. In general, the key factors that are closely related to the construction of railway networks and the opening of stations include economic indicators (such as GDP or per capita GDP); industrial development dynamics; and urban spatial characteristics (such as built-up area, population density, etc.). Therefore, in the planning and development of railway station areas, it is necessary to take into account the impacts of metropolitan areas and urban construction to ensure that the sustainable development of station areas harmonizes with regional planning.

The continuous enhancement of the transportation node value and functional place value of the railway station area significantly promotes the smooth flow of resource elements within the metropolitan area; brings investment, people flow, and industrial agglomeration to the city, especially the booming development of modern service industry and advanced manufacturing industry; and strengthens the comprehensive competitiveness of the city and the metropolitan area [28,29]. In view of this, this study deeply recognizes that the level of sustainable development of railway station areas is not only affected by the value of transportation nodes and the value of urban places but also has a certain influential effect on the development of the city itself. Therefore, this study constructs an expanded three-dimensional assessment model of "transportation node–functional place–city support" (referred to as the NPS model). This new dimension of "city support" aims to explore the dynamic interaction between cities and railway station areas in a metropolitan area under different levels of development. As mentioned in previous studies, the three dimensions discussed in this study also interact with each other to promote the sustainable development of railway station areas. This is shown in Figure 2.

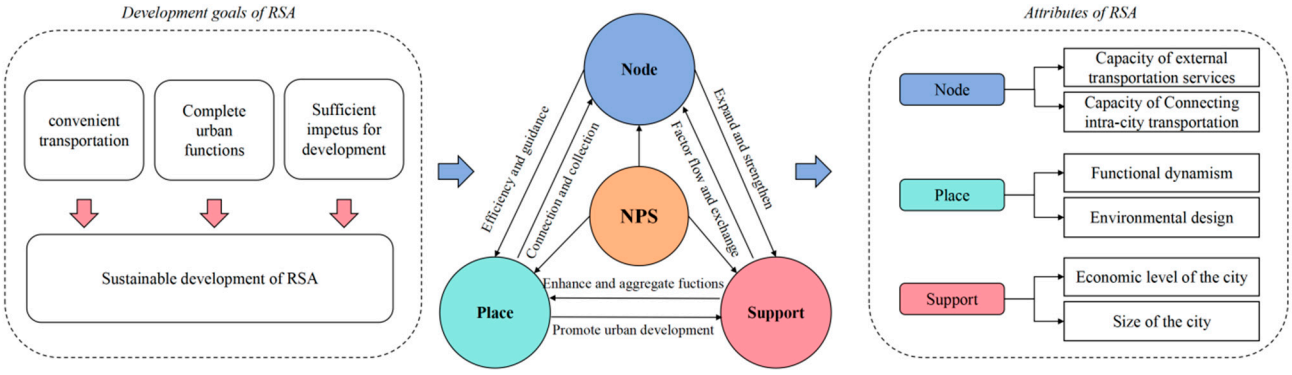


Figure 2. Node–Place–Support model.

2.2.2. Selection and Measurement of Evaluation Indicators for the NPS Model

The NPS model focuses on evaluating the value of nodes, places, and supports in the site area with the following systematic evaluation indicators. The connotation of each evaluation indicator and the calculation of the evaluation value are shown in Table 2. Among them are the Percentage of secondary industry (S2), Percentage of tertiary sector (S3), Size of built-up area (S4), and Number of resident population (S5). This is a newly introduced indicator in this study.

Table 2. NPS model evaluation indicators and calculation methods.

Category	Dimension	Indicator	Calculation Method	References
Node	Capacity of external transportation services	Station Design Scale	N1 = Number of platforms and lines of the railway station Number ≥ 10 platforms and 18 lines x1 = 1.0; 10 platforms and 18 lines ≥ number > 6 platforms and 10 lines x1 = 0.6; 6 platforms and 10 lines ≥ number > 4 platforms and 8 lines x1 = 0.4; 4 platforms and 8 lines ≥ number > 2 platforms and 4 lines x1 = 0.2; Number ≤ 2 platforms and 4 lines x1 = 0.1	Zou, Z.; Tang, Y. (2023) [30]
		Degree Centrality	N2 = Degree of center in the traffic network (Only the number of trains in the metropolitan area is calculated)	Wei, S.; Wang, L (2023) [31]
		Train frequ ency	N3 = Total number of daily departures or stops of high-speed trains, city trains, and trains	Dou M, Wang Y (2021) [10] Zhang, Y.; Marshall, S. et al. (2019) [11] Su, S.; Zhang, H.; Wang, M. et al. (2021) [12] Zou, Z.; Tang, Y. (2023) [30]
	Capacity of Connecting intra-city transportation	Distance to city center by public transportation	N4 = Fastest time by public transport from the railway station to the city center	Zou, Z.; Tang, Y. (2023) [30]
		Distance to city center by car	N5 = Fastest drive time from the railway station to the city center	
		Number of bus routes that can be used for transfers	N6 = Number of bus routes within the railway station area (including railway lines)	Dou M, Wang Y. (2021) [10] Zou, Z.; Tang, Y. (2023) [30]
Place	Functional dynamism	Density of POI	P1 = Density of POI for different functional categories in railway station area	Zhang ZJ et al. (2022) [32]
		POI function mixing degree	P2 = Mixing entropy of POI of different functional categories in railway station area	Wei, S.; Wang, L. (2023) [31]
		Density of enterprises	P3 = The ratio of the number of POI of the company to the area of the railway station	
	Environmental design	Density of the road network	P4 = The ratio of the length of the network to the area of the railway station	Su, S.; Zhang, H.; Wang, M. et al. (2021) [12] Zhang ZJ et al. (2022) [32]
		Density of green spaces	P5 = The ratio of the number of POI in the park to the area of the railway station	Zhang ZJ et al. (2022) [32]
Support	Economic level of the city	GDP	S1 = GDP of the city where the railway station is located	Zou, Z.; Tang, Y. (2023) [30]
		Percentage of secondary industry	S2 = Proportion of secondary industries in the city where the railway station is located	newly introduced indicator
		Percentage of tertiary sector	S3 = Proportion of tertiary industries in the city where the railway station located	newly introduced indicator
	Size of the city	Size of built-up area	S4 = The area of developed land within the administrative region of the city where the high-speed railway station is located	newly introduced indicator
		Number of resident population	S5 = Total permanent population of the city where the railway station located	newly introduced indicator

(1) Transportation Node Dimension

To comprehensively assess the transportation capacity of railway station areas (RSAs) in a metropolitan region, it is essential to consider both the external transportation service capabilities and the internal transportation connectivity and interchange capabilities of the railway station area. Consequently, this study selects six evaluation indicators: station design scale, point centrality, train frequency, distance to downtown via public transportation, distance to downtown by car, and the number of public transportation routes.

We employed degree centrality to identify the number of direct connections of RSAs with other nodes within the urban agglomeration [33]. Oldham et al. (2019) found that, unlike betweenness and closeness centralities, which depend on the entire network structure, degree centrality focuses solely on the direct connections of a node. This characteristic can be advantageous when emphasizing local network attributes rather than global network properties [34]. In our analysis, we conceptualized RSAs as nodes and the routes as edges connecting these nodes. We utilized social network analysis (SNA) and UCINET software (version of 6.661) to compute the degree centrality for each RSA. It is important to note that the scope of the analysis was limited to the Guangzhou metropolitan area, excluding traffic data between the study stations and stations in other cities. The calculation formula for degree centrality is as follows:

$$C_i = \frac{1}{N-1}\sum_{i=1}^{N} K_i \quad (1)$$

where C_i denotes the centrality of the point degree of railway station i, N denotes the number of railway stations, and K_i denotes the number of other railway stations to which railway station i is directly connected.

(2) Functional Place Dimension

In terms of place dimension, this study follows the "three-Ds" principle of TOD: density, diversity, and design [35] to evaluate the attractiveness of RSAs. Based on previous studies [30–32], the POI density, functional mix, and enterprise density are selected to indicate the intensity and diversity of functional development in the region. Among them, enterprise density can reflect the intensity of enterprise construction and the availability of jobs in the region, which indirectly reflects the vitality of crowd gathering in the region. In terms of design, grid selection density and green space density are chosen to characterize the built environment of the site.

(3) City Support Dimension

The city support dimension reflects the level of sustainable economic and industrial agglomeration in the city where the railway station is located. The processes of industrialization and urbanization, industrial division of labor, people's quality of life, and socio-economic conditions in the metropolitan area are inextricably linked to the development of rail transit networks and stations [36]. The construction of railway stations and line networks drives the population growth and population mobility of the surroundings and even the whole city and has a greater impact on the aggregation and development of the secondary and tertiary industries (especially the manufacturing industry and the productive service industry) [37]. The city support dimension reflects, at the macro level, the development level of the economy, population, and industrial structure of the city where the station area is located. On the other hand, it measures the relationship between the construction of the station area and the characteristics of the urban spatial structure. It is worth noting that the city support value dimension studies the impact of the level of city development on the station area, and the indicator data are calculated for the city where the station area is located, rather than the station area range.

2.3. Data Sources

Four types of public datasets were utilized in this study, obtained from various sources, including Baidu Encyclopedia (https://baike.baidu.com/, accessed on 31 Deccember 2023), the Railway 12306 official website (https://www.12306.cn/index/, accessed on 31 Deccember 2023), Gaode Map's official website (https://www.12306.cn/index/, accessed on 31 Deccember 2023), and the Statistical Bulletin on National Economic and Social Development.

Baidu Encyclopedia provided information on the platform dimensions at individual stations, which was subsequently validated through empirical research. The Railway 12306 official website dataset offered insights into daily train frequencies originating from and transiting through each station, enabling the calculation of nodal centrality for each station within the metropolitan transportation network. Gaode Map facilitated the measurement of distances and provided access to points of interest (POI) data. Additionally, data from publicly accessible government sources, such as municipal statistical yearbooks, yielded information on city economic metrics, population statistics, and construction scales.

2.4. Calculation and Categorization of the RSA Levels of Sustainability

The sustainable development of a railway station area is affected by multiple factors, and different factors have different degrees of influence on its development, which are needed to determine its importance. This paper adopts the entropy-weighted method (EWM) and hierarchical analysis to determine the weights of three levels of indicators. The term "entropy" comes from information theory for measuring the level of dispersion or randomness in a dataset. Indicators with lower entropy values indicate higher concentration and are deemed more crucial. The entropy value method is based on information entropy quantitative indicators, objective and precise and weakly dependent on the samples.

Subsequently, combining the literature and experts' opinions, the Analytic Hierarchy Process was used to determine the weights of the dimensions of the NPS model, and 18 experts were invited to participate, including 8 experts from universities and 10 experts from the Urban Planning and Design Institute.

2.4.1. Calculation

Since the dimension of transportation nodes, the dimension of functional places, and the dimension of city support belong to three relatively independent dimensions, this study calculates the weights of the three independently.

(1) Calculation method for the weights of the indicators

Normalizing the data helps to reduce the skewness of their univariate distribution and improves the comparability between the data. Equations (2) and (3) used for the calculations are shown below:

$$x_i' = \begin{cases} \frac{x_i^{\lambda}-1}{\lambda}, if\lambda \neq 0; \\ \log x_i, if\lambda = 0. \end{cases} \quad (2)$$

where x_i' is the transformed variable; λ is the transformation parameter, ranging from -5 to 5. The optimum value of λ is obtained using the maximum likelihood estimate:

$$x^* = \frac{\max(x_i') - x_i'}{\max(x_i') - \min(x_i')} \quad (3)$$

Calculation of the proportion of the i-th sample for the j-th indicator, where n is the number of samples.

$$P_{ij} = \frac{X_{ij}'}{\sum_{i-1}^{n} X_{ij}'} \quad (4)$$

Calculation of the entropy of the *j*-th indicator, where k is a constant, and $k = \frac{1}{ln(n)}$ to ensure that the entropy value E_j falls within the range of 0 to 1.

$$E_j = -k\sum_{i=1}^{n} P_{ij} ln(P_{ij}) \quad (5)$$

Calculation of the difference coefficient for the *j*-th indicator. The larger the difference coefficient, the more information the indicator provides, and accordingly, it should be assigned a greater weight.

$$D_j = 1 - E_j \quad (6)$$

Calculation of the weight for the *j*-th Indicator, where m is the number of indicators. Through these steps, the weights w_j for each indicator can be obtained, which can be used for further decision-making analysis.

$$w_j = \frac{D_i}{\sum_{j=1}^{m} D_i} \quad (7)$$

Taking the indicator degree centrality (N2) as an example, the result of its calculation is shown in Equation (8). C_i is the degree of center in the traffic network calculated according to Equation (1):

$$\mathrm{N2} = w_j \times \mathrm{C}_i \quad (8)$$

(2) Calculation method for the weights of the dimensions

Utilizing the Analytic Hierarchy Process (AHP) with a 1–9 scaling method (Table 3) to represent the strength of influence among the factors, a pairwise comparison of the relative importance of each factor within each layer to the objectives of the higher level is conducted to construct the discriminant matrices. By applying the pairwise comparison matrices, the input of subjective expert opinions is transformed into the output of objective weights for each dimension when the maximum eigenvalue of the matrix passes the consistency ratio test below 0.1.

Table 3. The scale and implication of the discrimination matrix.

Scale	Meaning
1	The two factors are equally important.
3	The former factor is slightly more important than the latter.
5	The former factor is significantly more important than the latter.
7	The former factor is strongly more important than the latter.
9	The former factor is extremely more important than the latter.
2, 4, 6, 8	Represents an intermediate level of importance between the adjacent judgments.
reciprocal	If the importance ratio of factor i to factor j is a_{ij}, then the importance ratio of factor j to factor i, $a_{ji} = 1/a_{ij}$.

The calculation formula for the Consistency Index (*CI*) is as follows:

$$CI = \frac{\lambda_{max} - n}{n - 1} \quad (9)$$

where λ_{max} is the maximum eigenvalue of the judgment matrix, and n is the order of the judgment matrix. Subsequently, find the corresponding Random Index (*RI*) value and calculate the consistency ratio (*CR*) according to the following equation:

$$CR = \frac{CI}{RI} \quad (10)$$

The measure of the level of sustainability in each dimension is obtained by summing the data of the indicators in that dimension and multiplying them by the corresponding weights. For example, the node dimension is calculated as shown in Equation (11):

$$N = \alpha(N1 + N2 + N3) + \beta(N4 + N5 + N6) \quad (11)$$

where α and β denote the weights of the dimension of the NPS model, respectively.

(3) Calculation method for the weights of the categories

According to the above indicator weights, the transportation node dimension (N), place function dimension (P), and city support dimension (S) of each railway station area can be calculated, and the data of the three dimensions can be summed up to obtain the comprehensive evaluation indices of sustainable development potential (X) of the railway station area (Equation (12)):

$$X = N + P + S \quad (12)$$

2.4.2. Classification

The original NP model classification method is shown in Figure 3 and Table 4, which classifies stations into five categories: equilibrium, equilibrium pressure, equilibrium dependence, non-equilibrium nodes, and non-equilibrium places. In this study, the city support dimension is added, and the evaluation results are projected into the 3D model to obtain three different coordinate maps. This study categorizes sites into eight major categories, as shown in Table 5, which can be further subdivided according to the specific conditions of the studied objects.

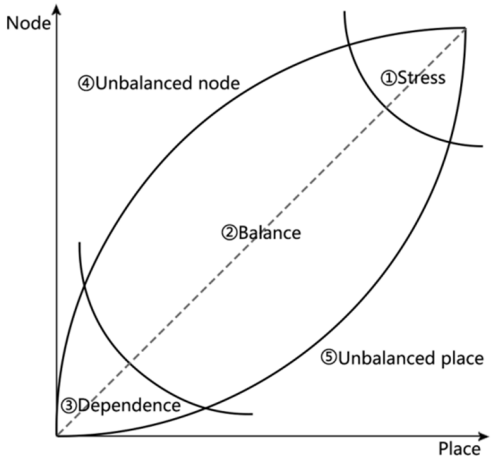


Figure 3. Corresponding coordinate positions of each type in the NP model classification approach.

Table 4. Original NP model classification.

Object	Node–Place	Type	Category
RSA	1, 2, 3	Balance(B)	Balance, Stress, Dependence
	4, 5	Unbalance(UB)	Unbalanced node, Unbalanced Place

The definitions and explanations of the eight types are as follows:

(1) B-B-B Type: When the node index, place index, and support index all match, it indicates that the RSA's transportation capacity and station area attractiveness are in line with the city's development direction, and the city's support is sufficient to sustain the anticipated urban development.

(2) B-B-UB Type: When the node index matches with the place index and support index but the place index does not match the support index, it means that the city's support is inadequate to sustain the attractiveness of the station area.
(3) B-UB-B Type: When the place index aligns with the node index and support index for development but the node index does not match the support index, it shows that the RSA's attractiveness and transportation capacity are in line with the city's orientation while there is a gap between the transportation capacity and the needs of the city system, which could lead to an imbalance in traffic and urban development.
(4) B-UB-UB Type: When the node index matches the place index but the support index does not match either, it suggests that the RSA's development has not effectively enhanced the city's competitiveness in the metropolitan area.
(5) UB-B-B Type: When the node index does not match the place index, it implies that the city's resources have not effectively contributed to the development of the RSA, which may limit the city's potential for development in the future metropolitan area.
(6) UB-B-UB Type: When only the node index and support index match, it reflects that the functional construction and attractiveness of the RSA need to be further strengthened to meet the needs of urban development.
(7) UB-UB-B Type: When only the place index and support index match, it indicates that the RSA's transportation capacity requires further planning and enhancement to align with the city's development requirements.
(8) UB-UB-UB Type: When the node index, place index, and support index all do not match, it shows that the planning of transportation capacity and attractiveness is seriously out of step with the city's development direction, and the city's support is insufficient to sustain the anticipated development. This situation could lead to chaos and imbalance in traffic and development, which is not conducive to enhancing the city's competitiveness in the metropolitan area.

Table 5. NPS model classification.

Object	Node–Place	Node–Support	Place–Support	Category	Definition
RSA	1, 2, 3	1, 2, 3	1, 2, 3	B-B-B	Balanced Type
	1, 2, 3	1, 2, 3	4, 5	B-B-UB	Place and Support Unbalanced Type
	1, 2, 3	4, 5	1, 2, 3	B-UB-B	Node and Place Unbalanced Type
	1, 2, 3	4, 5	4, 5	B-UB-UB	Support Unbalanced Type
	4, 5	1, 2, 3	1, 2, 3	UB-B-B	Node and Place Unbalanced Type
	4, 5	1, 2, 3	4, 5	UB-B-UB	Place Unbalanced Type
	4, 5	4, 5	1, 2, 3	UB-UB-B	Node Unbalanced Type
	4, 5	4, 5	4, 5	UB-UB-UB	Unbalanced Type

As depicted in Figure 3, the original NP model categorizes the state of Balance (B) into three substates: ① Stress, ② Balance, and ③ Dependence. Conversely, the category of Unbalance (UB) encompasses two substates: ④ Unbalanced node and ⑤ Unbalanced Place. Building upon this classification framework, the NPS model constructed in this study defines the subcategory classification method as shown in Figure 4, which comprises a total of 125 subcategories. These types represent the specific developmental aspects of the research subject along particular dimensions.

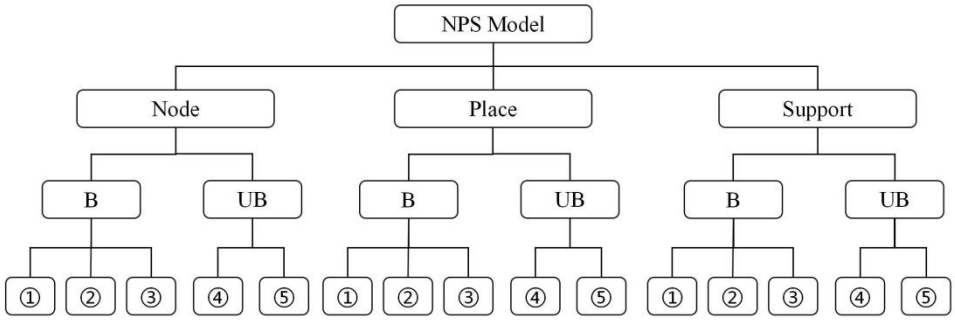


Figure 4. The classification combination method of the subcategories of the NPS model.

3. Results and Analysis

3.1. Node–Place–Support Model

3.1.1. Indicators

Through computation, it is evident that the maximum eigenvalues (λ_{max}) for the three sets of dimensions are 2.0000, 2.0000, and 2.0000, respectively. The consistency ratios (*CRs*) for these sets are all less than 0.1, indicating that the results are consistent.

Table 6 presents the weight allocation results for three dimensions and 16 constituent indicators. The weights of each variable under each dimension are relatively evenly distributed. Within the node dimension, both the station design scale (N1) and the number of interchangeable bus routes (N6) emerge as critical variables. The station platform design size serves as an indicator of the station's significance and service capacity [38]. The count of interchangeable public transportation routes offers insights into the station's accessibility and service scope within the city context, which, in turn, indirectly signifies the extent of development and economic vitality of the city's public transportation network. The POI density is identified as the most pivotal indicator within the place dimension. In the city support dimension, the proportion of the tertiary industry emerges as the predominant determinant, aligning with previous findings that demonstrated a robust correlation between the development of a train station area and the proportion of the tertiary industry in the city landscape [39].

Table 6. Indicator weights for the NPS model.

Category	Dimension	Weight	Indicator	Weight
Node	Capacity of external transportation services	0.5649	N1	0.4657
			N2	0.2294
			N3	0.3048
	Capacity of Connecting intra-city transportation	0.4351	N4	0.1707
			N5	0.2024
			N6	0.6269
Place	Functional dynamism	0.5949	P1	0.5064
			P2	0.1029
			P3	0.3907
	Environmental design	0.4051	P4	0.4496
			P5	0.5504
Support	Economic level of the city	0.5761	S1	0.3611
			S2	0.1880
			S3	0.4509
	Size of the city	0.4239	S4	0.4433
			S5	0.5567

3.1.2. Dimensions

Table 7 provides the descriptive statistics for three dimensions. By comparing the values of the node, place, and support dimensions, it was found that the average value of the node value is higher than that of the place value, which indicates that most of the sites in the 12 samples need to further improve the construction of the place value. In addition, the degree of dispersion of the indicators under the support dimension is large, indicating that there is a large gap between the development levels of the four cities in the metropolitan area.

Table 7. Descriptive statistics for the node, place, and system support indicators.

	Minimum Value	Maximum Value	Average Value	Standard Deviation
Node	0.0890	0.7390	0.3336	0.2180
Place	0.0425	0.9010	0.2920	0.2782
Support	0.0709	0.8917	0.3417	0.3115

The Table 8 correlation analysis shows that there is a correlation among the three dimensions of the NPS evaluation model. It shows a significant positive correlation between the three. This result is consistent with the purpose of setting up the model now and also shows that the model is valid.

Table 8. Correlation analysis between the three dimensions of transportation nodes, place functions, and city support and the overall evaluation results.

	Node	Node	Node	Comprehensive Evaluation
Node	1	-	-	-
Place	0.7007 **	1	-	-
Support	0.5659 *	0.8587 **	1	-
Comprehensive evaluation	1	0.9570 **	0.9232 **	1

Note: ** $p < 0.05$; * $p < 0.1$.

3.2. Evaluation Results Based on the NPS Model

Figure 5 demonstrates the nodes, places, support values and overall evaluation results for each station area. Of these, the three RSAs (Guangzhoudong Railway Station, Guangzhoubei Railway Station, and Xintang Station) in Guangzhou City scored significantly higher in terms of sustainability levels than the other nine RSAs. This also shows the impact of the metropolitan area location of the site on the results.

The evaluation results of the three dimensions of the 12 research samples are shown in Figure 6. As shown in Figure 6a, most of the RSAs have balanced node and place relationships. However, Foshan West Station and Zhaoqing East Station are unbalanced nodes. The main reason for this is that both sites are positioned as urban core sites, but currently, there are fewer supporting facilities around the sites, and the development intensity is low. Therefore, it causes the mismatch between the transportation capacity of the stations and the construction of the surrounding city space. According to the results in Figure 6b,c, the stations in the same city are basically at the same level of development. Compared to other stations, the stations located in Guangzhou and Foshan are closer to the balanced state. This shows that the higher the level of city development, the greater the impact on the level of sustainability of a RSA. Second, there are three out of balance sites in the support node scatterplot (Figure 6c) compared to the scatterplots of the other two dimensions. This indicates that the mismatch between the function of transportation nodes and the level of city development of the 12 study samples is higher than the other two dimensions combined graphs and also indicates that the level of city development in

the context of the metropolitan area has more impact on the generation of node values in the railroad station area.

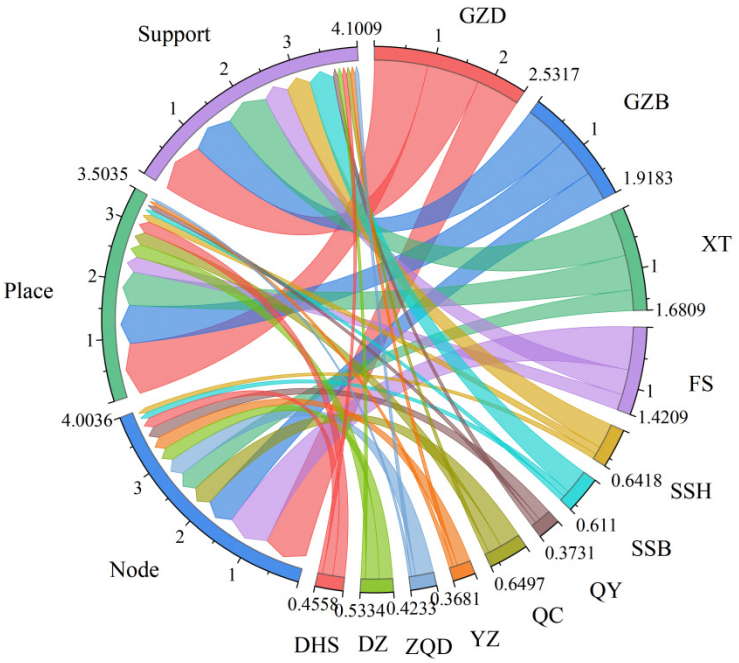


Figure 5. Evaluation results and ranking of the 12 study samples. Note: GZD: Guangzhoudong Railway Station; GZB: Guangzhoubei Railway Station; XTS: Xintang Station; FSX: Foshanxi Railway Station; SSN: Sanshuinan Railway Station; SSB: Shishanbei Railway Station; QYS: Qingyuan Railway Station; QCS: Qingcheng Railway Station; YZS: Yinzhan Railway Station; ZQD: Zhaoqingdong Railway Station; DZS: Duanzhou Railway Station; DHS: Dinghushan Railway Station.

In addition, it can be found that the development of inaccessible railway station areas in the same city also has great differences. For example, the development of Guangzhou East Station is too saturated, and the coordination between the transportation nodes and city support of Guangzhou North Station and Xintang Station is still to be improved.

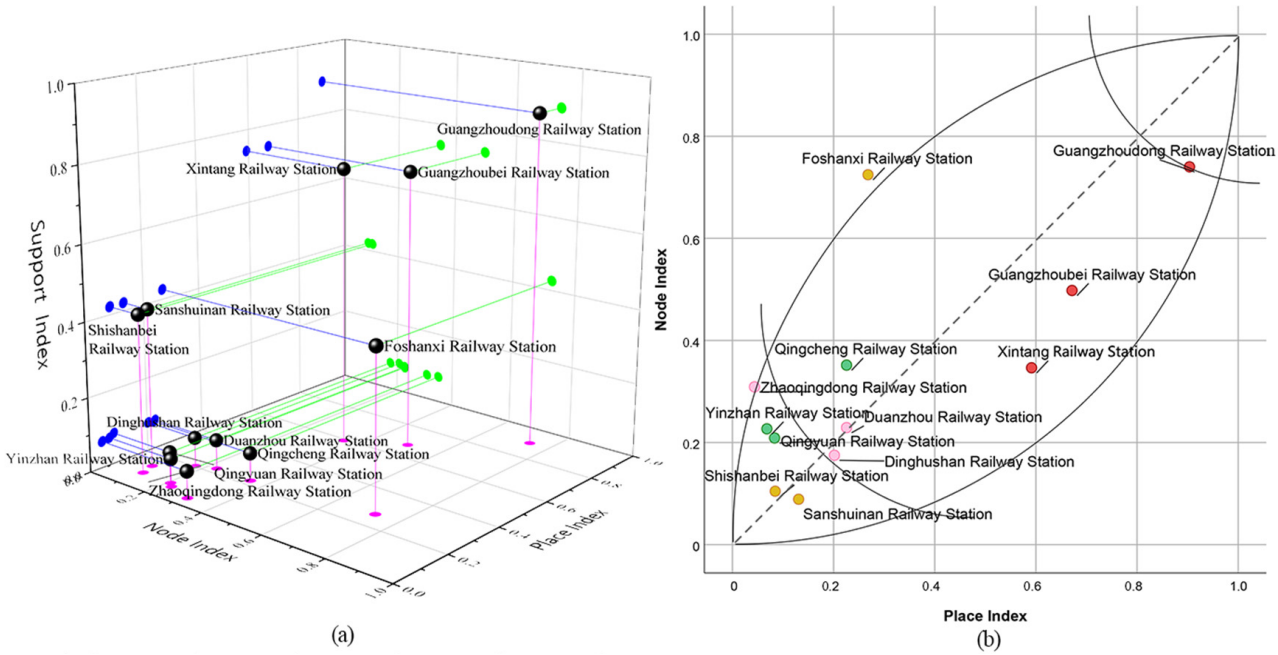


Figure 6. *Cont.*

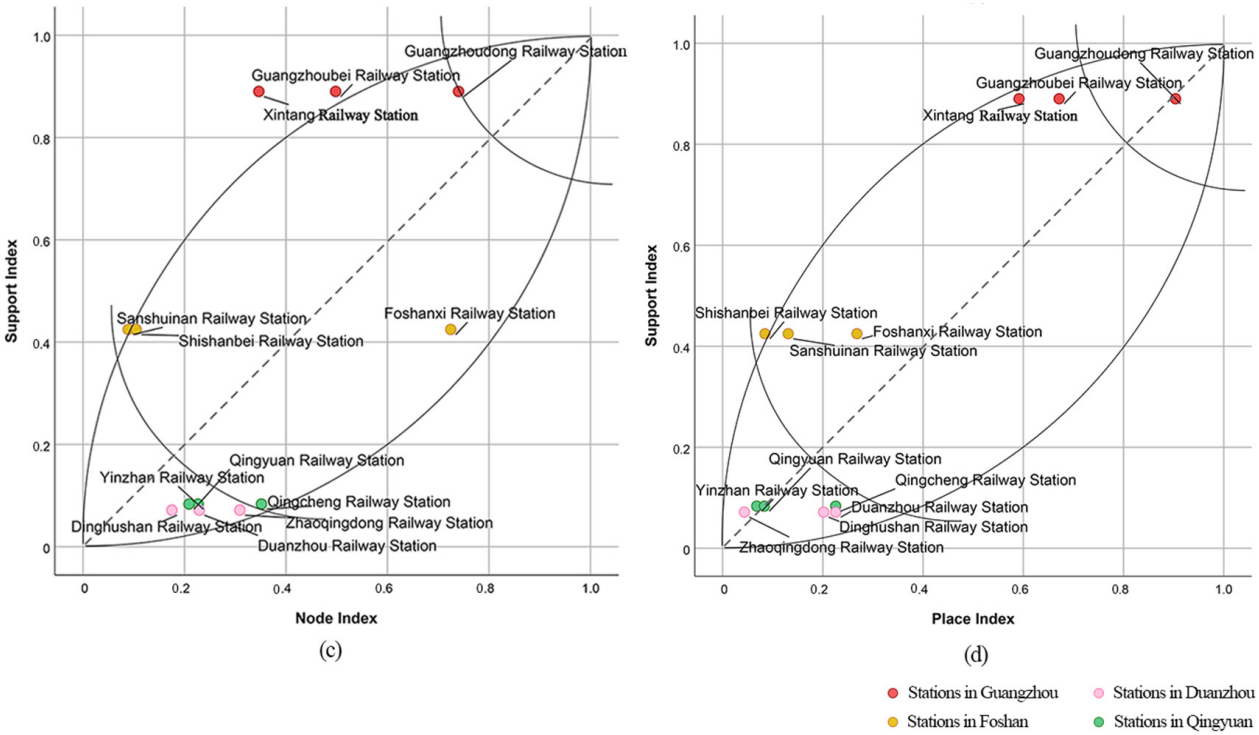


Figure 6. Scatterplots of nodes, places, and city support indicators in the railway station area in the NPS model ((**a**) 3D scatterplot, (**b**) Node–Place scatterplot, (**c**) City Support–Node scatterplot, and (**d**) City Support–Place scatterplot).

3.3. Classification Results

In order to deeply explore the synergistic effects of the nodes, places, and city support, the samples of 12 railway station areas in the Guangzhou metropolitan area were divided into four major categories and seven minor categories by analyzing the relationship between the three dimensions through coordinate projection. Among them, B-B-B station area development is the Balanced type, UB-B-B needs to improve the coordination of node and place, type B-UB-B has an imbalance between node and support, and type B-B-UB needs to improve the coordination of place and support. The categorization results of the 12 study subjects are shown in Table 9.

Table 9. NPS 3D model analysis and categorization results.

RSA	NP	NS	PS	Category	Subcategory
Guangzhoudong Railway Station	1	1	1	B-B-B	NPS all Stressed
Guangzhoubei Railway Station	2	4	2	B-UB-B	City Support Developed Class Balanced
Xintang Station	2	4	2	B-UB-B	City Support Developed Class Balanced
Foshanxi Railway Station	4	2	2	UB-B-B	Node Developed Class Balanced
Sanshuinan Railway Station	3	4	2	B-UB-B	City Support Dominated Class-Dependent
Shishanbei Railway Station	3	2	4	B-B-UB	City Support Dominated Class-Dependent
Qingyuan Railway Station	3	3	3	B-B-B	NPS-Dependent
Qingcheng Railway Station	2	3	3	B-B-B	City Support-Deficient
Yinzhan Railway Station	3	3	3	B-B-B	NPS all Dependent
Zhaoqingdong Railway Station	4	3	3	UB-B-B	Node-Deficient
Duanzhou Railway Station	2	3	3	B-B-B	City Support-Deficient
Dinghushan Railway Station	2	3	3	B-B-B	City Support-Deficient

Subcategory one is the NPS Stressed type, with the representative case of Guangzhou East Station, where the nodes, places, and city development levels are all in a saturated state. These RSAs belong to the core transportation node of the city and even the province, the use of time is relatively longer, the traffic carrying capacity has been given full play to, most of the land within the station area has been developed, and the degree of functionality is of the high degree of perfection, and the station area development and city development synchronization is very high.

Subcategory two is named the City Support Developed Class Balanced type, such as Guangzhou North Station and Xintang Station. The node and place values of these sites have been fully realized, and their values in all dimensions will be further enhanced in the future as the sub-core of the metropolitan area.

Subcategory three is the Node Developed Class Balanced type; relatively speaking, the transportation node value of this cluster of station areas has a greater impact on the overall level of sustainable development, but the surrounding land use level and industrial aggregation capacity are expected to be further enhanced in the process of city development.

Subcategory four is the City Support Dominated Class-dependent type, such as Sanshui South Station and Shishan North Station; this cluster of station areas has received greater support from the city in the development process, but the value of the transportation nodes and the functional value of the place still have a lot of room for improvement.

The NPS-dependent type represented by Qingyuan Station and Yinzhan Station belongs to the fifth subcategory, with a low degree of interdependence between nodes, places, and cities, mainly due to the low degree of convenience of connection between the station and the city, which makes it difficult to drive the functional complexity of the station area and the gathering of people; the station platform is designed on a smaller scale and is able to bear less traffic and transportation than other station areas.

Subcategory six is the City Support-deficient type, which has node value and place value coordination but a low level of city development.

The Node-deficient type, such as Zhaoqing East Station, belongs to the seventh subcategory. These stations are relatively coordinated in their development between place value and level of city development but exhibit a weak transportation node function in the metropolitan area rail transit line network. Overall, only Guangzhou North Station, Xintang Station, and Foshan West Station are more balanced and have a high level of sustainable development, while the rest of the station areas still need to be upgraded.

4. Discussion

Currently, China's metropolitan areas are entering a period of rapid development, but the construction of rail transit stations and the surrounding land is relatively lagging behind, with varying levels of development [40]. In order to promote the sustainable development of railway station areas in the new context of the metropolitan area, this study introduces the city support dimension, constructs the transportation node–lace function–city support model (NPS model), and selects appropriate evaluation indicators and measurement methods to ensure that they can comprehensively and objectively reflect the sustainable development potential of railway station areas. The sustainable development potential of 12 railway stations in four cities in the Guangzhou metropolitan area is empirically analyzed, and the development types of different station areas are summarized through three groups of classification methods with different dimensions.

The results of the study show that, overall, the 12 study samples in the Guangzhou metropolitan area can be divided into four major and seven minor categories, namely the NPS Stressed type, City Support Developed Class Balanced type, Node Developed Class Balanced type, City Support Dominated Class-Dependent type, NPS-Dependent type,

City Support-Deficient type, and Node-Deficient type. Similar to the findings of previous studies, there are multiple unbalanced developments in the Guangzhou metropolitan area. The new findings include the expansion of site types from five to eight identified by the NP model and can be further preferred based on specific performance. The main reason for the low level of sustainability in most of the site areas is the uncoordinated development of the node dimension and the city support dimension.

The six RSAs in the center of the metropolitan area are already oversaturated, which is a problem that should be taken into account for future development, but of course, it is also related to the opening time of the stations. As an important station under the metropolitan area strategy for a long period of time, its development status represents the competitiveness of the city and the metropolitan area to a certain extent. The other six RSAs that are in cities that are not the center of the metropolitan area appear to mostly have B-B-B status. However, the breakdown of the typology shows that there is a low level of dependence between transportation, place, and city support. This is related to the importance of the site in the transportation network, the degree of surrounding development and land use patterns, and the level of economic vitality of the city.

The influencing factors in the role relationships and optimization strategies for different types of sites will be further discussed later.

4.1. Evaluation of the Influencing Factors in the Model

In addition to the discussion of the final results, the interplay between the evaluation indicators deserves further exploration. The normalized indicator data were subjected to a Pearson correlation coefficient test, and the outcomes are depicted in Figure 7. The analysis revealed a highly significant correlation among certain variables. Nonetheless, the pronounced correlation observed between these indicators does not pose a concern [41]. For example, there is a high correlation between the station size and the city's economic development indicators, because the construction of the railroad station for the city where it is located not only provides convenient transportation conditions but also effectively drives the city's economy, resulting in a "multiplier effect" [42]. Moreover, in the study, different indicators of each dimension will be given different weights and then used to calculate the final value of the sustainable development level.

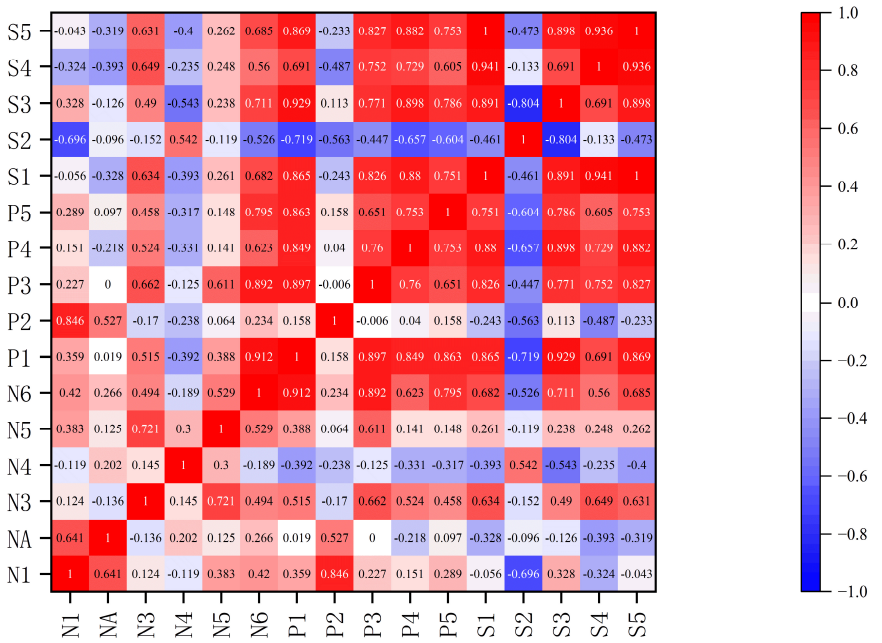


Figure 7. Correlation analysis between indicators.

One of the concerns is that the proportion of secondary industry in cities (S2) shows a negative correlation with all other indicators (except N4). This is because, with the advancement of urbanization, many cities have experienced a shift in economic structure from being dominated by the secondary industry to being dominated by the tertiary industry. The tertiary industry is more dependent on the flow of people and information. The railroad station, as an important transportation hub serving the tertiary industry, has increased in size and surrounding construction, which has increased the promotion of the city's tertiary industry. The second reason is influenced by land use and planning. In the process of metropolitan area construction, the secondary industry is gradually shifted from the city center to the outskirts of the city, and the change in land use also affects the scale of the railroad station and its surrounding construction.

In contrast, there is a positive correlation between POI density (P1) and most of the indicators, and the correlation coefficient with seven indicators reaches more than 0.8. This indicates that sites with high POI density are hotspots of economic activities in a city, demonstrating good urban planning and quality of life. It also reflects the synergistic effect and multifunctionality of city development.

4.2. Implications for RSA Planning

To optimize railway station area development, tailored strategies are essential to harmonize nodes, places, and city systems. The aim is to ensure station area accessibility and functionality, complementing the city division of labor and industry. By implementing targeted measures, we strengthen the metropolitan network's transportation, industrial, and elemental integration, fostering sustainability from the local to regional scale. The proposed strategies are:

(1) For saturated areas like Guangzhou East Railway Station, with its advanced transport node and developed surroundings, the focus should be on enhancing traffic and passenger flow efficiency, promoting integrated ticketing, and colocation processes. Investment in public amenities and environmental quality will establish a quality urban benchmark. Adjusting the industrial mix to favor knowledge-intensive services is advised, with caution against overdevelopment. The case of London's King's Cross Central area serves as a paradigm for efficient renewal under the concept of station–city integration. The renewal model of this area emphasizes the promotion of regional collaboration and the optimization of city spatial patterns through the transformation of high-speed railway stations, set against the backdrop of city integration. This approach effectively avoids overdevelopment and ensures the rational utilization and sustainable development of the urban space [43].

(2) An empty-type or a certain dimension of empty-type station area is basically located in the metropolitan area of non-core cities. These RSAs should leverage their unique resources, such as commerce, culture, or nature, in conjunction with efficient rail transit. This approach will foster advanced manufacturing and services, driving industrial clustering and attracting passenger and economic flows, thereby enhancing the station area's vitality and sustainability. For example, Shibuya Station in the Tokyo metropolitan area exploits its role as a transport node and its association with youth culture and fashion trends. It has emerged as a cultural hub and tourist attraction in Japan and Asia. This has significantly fostered the creation and growth of new urban areas [44].

(3) For railway station areas that are in a state of equilibrium or have a significant advantage in one dimension, characterized by a long history of opening and a rich variety of rail transit types, these RSAs play a crucial role as nodes in the transportation network between the central city and neighboring cities. Strategic planning

and industry cultivation can define their role in the metropolitan economy, forming distinctive industrial chains. The consideration of each station area's proximity to the city center, development status, and support is crucial for a balanced and collaborative approach, avoiding industry homogenization and promoting regional economic synergy, as exemplified by the construction of the Tsukuba Express in the Tokyo metropolitan area. Through its railway stations, it facilitates the convenient movement of researchers, students, and business professionals, thereby enhancing industrial connectivity. The areas around each station of the Tsukuba Express have seen the aggregation of variously scaled industries, such as biotechnology, information technology, and environmental science. These industries complement other regions within the Tokyo metropolitan area, promoting the refinement and upgrading of the metropolitan industrial chain [45].

4.3. Applicability and Promotion of the NPS Model

The sustainable development assessment model and optimization strategies for railway station areas proposed in this study provide important theoretical guidance and practical references for the development of railway station areas in the Guangzhou metropolitan area. However, due to the differences in economic development levels, geographical characteristics, and transportation network structures among different metropolitan areas, the applicability and adaptability of the model require further exploration.

The economic development level is a key factor affecting the sustainability of railway station areas. For less developed urban agglomerations, the construction of a transportation infrastructure and the improvement of public service facilities are the foundation for the sustainable development of railway station areas. Therefore, when applying the model, attention should be paid to indicators such as transportation accessibility and the supporting public service facilities, and corresponding optimization strategies should be formulated, such as increasing investment in infrastructure construction and improving the supporting public service facilities.

Geographical characteristics and transportation network structures also affect the sustainable development of railway station areas. For example, mountainous cities need to pay attention to indicators such as geological disaster prevention and control and ecological environment protection and formulate corresponding optimization strategies, such as strengthening geological disaster monitoring and warning and developing ecotourism. Plain cities need to pay attention to indicators such as spatial planning of the city and industrial upgrading and formulate corresponding optimization strategies, such as optimizing urban spatial layout and developing high-end service industries.

For urban agglomerations with developed transportation networks, the functional orientation of railway station areas may be more diversified, requiring attention to indicators such as transportation transfer, industrial agglomeration, and urban renewal and formulating corresponding optimization strategies, such as developing comprehensive transportation hubs, building industrial parks, and carrying out urban renewal.

In addition to the above factors, each city also has different characteristics in terms of ecological environment, history and culture, and tourism resources. Therefore, when applying the model proposed in this study, it is necessary to design evaluation indicators with local characteristics according to the specific situation of each city. For example, for cities with rich tourism resources, indicators such as the number of tourists and tourism income can be added.

In summary, the sustainable development assessment model and optimization strategies for railway station areas proposed in this study have a certain universality but need to be adjusted according to the actual situations of different urban agglomerations when applied to better guide the sustainable development of railway station areas.

4.4. Strength, Limitations, and Future Prospects

This investigation presents a nuanced examination of railway station area development within various metropolitan city contexts, offering distinct insights and methodological advancements over prior research. Notably, the study pioneers an integration of station area sustainability with city construction levels, highlighting the pivotal influence of city size and economic structure, particularly industrial makeup, on station area sustainability. This holistic approach underpins a fresh theoretical framework for exploring station area development dynamics.

Innovations in indicator selection and data processing, such as the use of point degree centrality to quantify station area significance and enterprise density as a proxy for population aggregation, enhance the study's practicality and efficacy. The application of web crawling and social network analysis for data collection and analysis represents a significant departure from traditional empirical methods, offering a new paradigm for addressing previously qualitative evaluation challenges. The NPS model constructed in this study differs from the existing NP model and its extended versions, as detailed in Table 10. The NPS model reveals the intrinsic connection between city support and the functional roles of station areas from a macro perspective, enriching our understanding of station area development. It also provokes further reflection on the new changes and dominant factors in stations and surrounding urban spaces against the backdrop of regional integration. These findings enable the customization of optimization strategies for various types of stations, supporting sustainable development in metropolitan areas.

Table 10. Comparison of the NPS model with other models.

Name	Extension	Indicators	Focus
Node–Place–Support	City Support	GDP, Percentage of secondary industry, Percentage of tertiary sector, Size of built-up area, Number of resident population	Focus on the impact of varying urban development levels on station within the context of metropolitan areas.
Node–Place–Network Dou M, Wang Y (2021) [10]	Network Centrality	Degree centrality, Betweenness centrality	Focus on the relationship between stations and urban transportation systems, identifying stations with systemic mismatches.
Node–Place–Design Zhang, Y.; Marshall, S. et al. (2019) [11]	Design	Pedshed ratio, Intersection density, Accessible network length	Focus on the pedestrian environment around the stations from a microscopic perspective
Node–Place–Functionality Su, S.; Zhang, H.; Wang, M. et al. (2021) [12]	Functionality	Serviceability, Accessibility, Walkability	Focus on the functions closely related to walking and cycling around the stations from a microscopic perspective

The limitations of the current study primarily stem from the relatively small sample size, which encompasses only 12 RSA cases. This limited sample may not adequately represent the diverse challenges faced by RSAs in metropolitan areas. To enhance the robustness of the findings, an increased sample size would be advantageous. Given the rapid development trends of global urban agglomerations, future research should conduct comparative analyses of the sustainability levels of RSAs across various developmental periods. This will require an in-depth investigation into the underlying causes of observed

changes, the evolutionary trends, and the key factors influencing sustainable development. Furthermore, the focus on the Guangzhou metropolitan area may restrict the generalizability of the model. We also recognize that indicators such as closeness centrality and betweenness centrality could serve as valuable supplements in future research, providing a more comprehensive network analysis. Subsequent studies should consider incorporating a broader array of evaluation indicators and expanding the research to include other metropolitan areas with different urbanization patterns and transportation systems to further validate the model's applicability.

Additionally, the binary classification approach utilized in this study may oversimplify the complex dynamics of RSA sustainability. To address this limitation, future research should aim to encompass all station areas within the Guangzhou metropolitan region. It is also noted that the study did not list all 125 possible subcategories due to space constraints; only seven subcategories were outlined based on the specific context of the research subject. Advanced classification methods, such as two-step clustering and K-means analysis, could be employed in future studies to refine the typologies and develop more nuanced transition strategies for achieving balance in RSA sustainability.

While predominantly quantitative, future research should integrate qualitative benefits to meet diverse stakeholder needs, enhancing decision-making. Despite its limitations, the study significantly contributes to the discourse on transportation–city interactions and provides a valuable tool for assessing station sustainability, setting a solid precedent for further inquiry and application.

5. Conclusions

This study investigates the sustainable development model of railway station areas (RSAs) within a metropolitan area, addressing three core issues initially proposed.

Firstly, the findings indicate that the factors influencing the development of RSAs in the metropolitan area differ from those identified in previous research. Notably, the study emphasizes the significance of city support and the interplay between city support, transportation capacity, and station attractiveness, all of which are vital for regional integration.

Secondly, the evaluation results facilitate a clear categorization of the research samples and delineate the various stages of RSA development. Some RSAs have achieved a level of sustainable development, while others necessitate enhancements in specific areas such as transportation capacity, attractiveness, or city support. This classification utilizes the extended NPS model, which has proven effective in quantifying the current development stage of each site and accurately identifying the dimensions requiring improvement.

Thirdly, concerning sustainable development strategies for RSAs, the study reveals that most sites within the Guangzhou metropolitan area require further optimization to attain sustainable development. Development strategies should be customized to meet the unique needs of each site, considering local conditions to promote synergistic development among urban transportation, urban space, and urban economic vitality.

The Guangzhou metropolitan area, recognized as one of the most developed city and transportation regions in China, can serve as a model for other metropolitan areas through the implementation of this framework. The sustained promotion of this model will not only enhance the awareness of planners and decision-makers regarding the significance of multi-factor synergy in the development of metropolitan areas but will also steer planning practices toward the objective of a "metropolitan area on rails". This study not only offers a reference for the future development of RSAs in global metropolitan areas but also contributes to the advancement of theories and practices in sustainable city development.

Author Contributions: Methodology, J.L. and Z.S.; Data curation, J.L., J.M. and Z.L.; Writing—original draft, J.L., J.M. and Y.H.; Writing—review & editing, Z.S. and R.Z.; Project administration, Z.S.; Funding acquisition, Z.S. and R.Z. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the National Natural Science Foundation of China [Grant number 52378039, 51978573 and 52408031].

Data Availability Statement: The raw data supporting the conclusions of this article will be made available by the authors on request.

Conflicts of Interest: The authors declare no conflicts of interest.

References

1. Cao, J.; Zheng, C.; Yang, M. Research on rail transit network system and its connection model in the metropolitan area. *Procedia—Soc. Behav. Sci.* **2013**, *96*, 1286–1292. [CrossRef]
2. Gao, Y.; Cui, X.; Sun, X. Land Use Characteristics of Commuter Rail Station Areas and Their Impact on Station Ridership: A Case Study of Japan Railways in the Tokyo Metropolitan Area. *Land* **2024**, *13*, 2045. [CrossRef]
3. Pang, L.; Ren, L.; Yun, Y. Research on the Interactive Development of Rail Transit and Spatial Structure in the London Metropolitan Area from the Perspective of Complex Systems. *J. Hum. Settl. West* **2022**, *37*, 98–105. (In Chinese) [CrossRef]
4. Russo, F.; Rindone, C.; Panuccio, P. External Interactions for a Third Generation Port: From Urban Sustainable Planning to Research Developments. *Int. J. Transp. Dev. Integr.* **2022**, *6*, 253–270. [CrossRef]
5. Zhang, B.; Zhao, Z.; Li, P.; Wang, Q.; Zhang, X. Research on Early Town Planning Using Spatial Syntax: A Case Study of Second-Tier Towns along the Middle East Railway. *Urban Dev. Stud.* **2018**, *25*, 128–133.
6. Zhu, Z.; He, Y.; Guo, X.; Zhang, Y.; Chen, J. Improved Huff Model for Estimating Urban Rail Transit Station Catchment Areas Considering Station Choices. *J. Adv. Transp.* **2021**, *2021*, 6374724. [CrossRef]
7. Wu, Y.; Shen, T.; Li, Y.; Kita, M.; Yoshida, Y.; Sho, K.; Yuan, L.; Yu, L.; Jiang, R.; Long, Y. Exploring Urban Railway Station-Based Attractiveness Considering Demographic-Specific Demands: Case Study of Odakyu Line, Japan. *Cities* **2025**, *158*, 105620. [CrossRef]
8. Bertolini, L. Nodes and Places: Complexities of Railway Station Redevelopment. *Eur. Plan. Stud.* **1996**, *4*, 331–345. [CrossRef]
9. Bertolini, L. Spatial Development Patterns and Public Transport: The Application of an Analytical Model in the Netherlands. *Plan. Pract. Res.* **1999**, *14*, 199–210. [CrossRef]
10. Dou, M.; Wang, Y.; Dong, S. Integrating Network Centrality and Node-Place Model to Evaluate and Classify Station Areas in Shanghai. *ISPRS Int. J. Geo-Inf.* **2021**, *10*, 414. [CrossRef]
11. Zhang, Y.; Marshall, S.; Manley, E. Network criticality and the node-place-design model: Classifying metro station areas in Greater London. *J. Transp. Geogr.* **2019**, *79*, 102485. [CrossRef]
12. Su, S.; Zhang, H.; Wang, M.; Weng, M.; Kang, M. Transit-oriented development (TOD) typologies around metro station areas in urban China: A comparative analysis of five typical megacities for planning implications. *J. Transp. Geogr.* **2021**, *90*, 102939. [CrossRef]
13. Liao, J.; Wang, Z.; Li, J. Development Strategy of Integrated Hubs in Cluster Cities under the Background of Metropolitan Area–Taking Gaoming High-speed Railway Station in Foshan City as an Example. In *Traffic Governance and Spatial Remodeling—Proceedings of the Annual Conference on Urban Transportation Planning in China in 2020*; Foshan City Urban Planning and Design Institute: Foshan, China, 2020; p. 11. (In Chinese)
14. Nian, G.; Chen, F.; Li, Z.; Zhu, Y.; Sun, D.J. Evaluating the alignment of new metro line considering network vulnerability with passenger ridership. *Transp. Res. Part A Policy Pract.* **2019**, *15*, 1402–1418. [CrossRef]
15. Zhao, Y.; Li, L.; Zhang, Z.; Sun, D. Performance Evaluation for the Expansion of Multi-Level Rail Transit Network in Xi'an Metropolitan Area: Empirical Analysis on Accessibility and Resilience. *Land* **2024**, *13*, 1682. [CrossRef]
16. Diao, M.; Zhu, Y.; Zhu, J. Intra-city access to inter-city transport nodes: The implications of high-speed-rail station locations for the urban development of Chinese cities. *Urban Stud.* **2017**, *54*, 2249–2267. [CrossRef]
17. Zhou, B.; Hu, X.; Xiong, C. Differential Influences of High-Speed Railway Stations on the Surrounding Construction Land Expansion and Institutional Analysis: The Case of Taiwan and Hainan. *Land* **2024**, *13*, 10. [CrossRef]
18. Duan, J.; Yin, M. Planning layout and spatial interchange convenience of high-speed rail stations: An empirical study in the Yangtze River Delta region. *Urban Plan.* **2014**, *38*, 44–50. (In Chinese)
19. Jacob, T.J. Urban Quality in High-speed Train Station Area Redevelopment: The Cases of Amsterdam Zuidas and Rotterdam Centraal. *Plan. Pract. Res.* **2008**, *23*, 383–401. [CrossRef]

20. Sorensen, A. Land readjustment and metropolitan growth: An examination of suburban land development and urban sprawl in the Tokyo metropolitan area. *Prog. Plan.* **2000**, *53*, 217–330. [CrossRef]
21. Zhao, Q.; Chen, G. Research on the impact of railroad station area location on the development of surrounding areas—An empirical analysis based on Beijing-Shanghai and Wu-Guangzhou lines. *Urban Plan.* **2015**, *39*, 50–55. (In Chinese)
22. Beckerich, C.; Benoit, S.; Delaplace, M. Are the reasons for companies to locate around central versus peripheral high-speed rail stations different? The cases of Reims central station and Champagne-Ardenne station. *Eur. Plan. Stud.* **2019**, *27*, 574–594. [CrossRef]
23. Nakamura, H.; Ueda, T. The impacts of shinkansen on regional development. *Proc. WC* **1989**, *3*, 95–109.
24. Schütz, E. Stadtentwicklung durch Hochgeschwindigkeitsverkehr (Urban development by High-Speed Traffic), Konzeptionelle und Methodische Abs tzezum Umgangmit den Raumwirkungen des schienengebunden PersonenHochgeschwind igkeitsverkehr(HGV)als Beitrag zur L sung von Problemen der Stadtentwicklung. *Informationen Zur Raumentwicklung* **1998**, *6*, 369–383.
25. Hugo, P. HST-Railway Stations as Dynamic Nodes in Urban Networks. China Planning Network (CPN): Beijing, China, 2006; pp. 12–13.
26. Xiong, C.; Hu, Y.; Zhou, B.; Liu, X.; Luan, Q. Expansion of construction land around the high-speed rail station around the island in Hainan and its impact mechanism. *Trop. Geogr.* **2024**, *44*, 938–950. (In Chinese) [CrossRef]
27. Deng, T.; Gan, C.; Perl, A.; Wang, D. What caused differential impacts on high-speed railway station area development? Evidence from global nighttime light data. *Cities* **2020**, *97*, 102568. [CrossRef]
28. Liu, X.; Chen, W.; Chen, X.; Chen, J.; Cheng, L. Analyzing sustainable competitiveness of inter-city coach from the impact of high-speed railway opening in Jiangsu Province, China. *Socio-Econ. Plan. Sci.* **2023**, *89*, 101710. [CrossRef]
29. Shi, S. Study on Land Development Strategy for Inter-city Railway Transport Hub: A Case Study of Heshengqiao Station of the Intercity Railway from Wuhan to Xianning. *Procedia—Soc. Behav. Sci.* **2016**, *216*, 172–180. [CrossRef]
30. Zou, Z.; Tang, Y. Evaluation of Sustainable Development Potential of High-Speed Railway Station Areas Based on "Node-Place-Industry" Model. *ISPRS Int. J. Geo-Inf.* **2023**, *12*, 349. [CrossRef]
31. Wei, S.; Wang, L. Classifying High-Speed Rail Stations in the Yangtze River Delta, China: The Node-Place Modelling Approach. *Appl. Spat. Anal. Policy* **2023**, *16*, 625–646. [CrossRef]
32. Zhang, Z.; Gao, S.; Chen, Y.; Xiao, Z.; Deng, J.; Xu, Q. TOD evaluation of urban rail transit based on improved node place model. *Transp. Res.* **2022**, *8*, 143–153+165. (In Chinese) [CrossRef]
33. Chen, S.; Zhuang, D. Evolution and Evaluation of the Guangzhou Metro Network Topology Based on an Integration of Complex Network Analysis and GIS. *Sustainability* **2020**, *12*, 538. [CrossRef]
34. Oldham, S.; Fulcher, B.; Parkes, L.; Arnatkevičė, I.A.; Suo, C.; Fornito, A. Consistency and differences between centrality measures across distinct classes of networks. *PLoS ONE* **2019**, *14*, e0220061. [CrossRef]
35. Wang, C.; Cai, R.; Geng, J.; Xiao, L.; Sun, Y. The TOD development mode of rail transit under the orientation of multi-network integration: Connotation, focus and system—Taking Suzhou as an example. *J. Urban Plan.* **2022**, *S2*, 135–141. (In Chinese) [CrossRef]
36. Chen, C.; Wei, B. High-speed rail and urban transformation in China: The case of Hangzhou East Rail Station. *Built Environ.* **2013**, *39*, 385–398. [CrossRef]
37. Ma, C. Research on land comprehensive development mode of railroad station area under the perspective of multi-body game--taking the example of high speed railway along the river. *J. Beijing Jiaotong Univ. (Soc. Sci. Ed.)* **2023**, *22*, 65–75. (In Chinese) [CrossRef]
38. Li, P.; Ge, Y. Evaluation of regional sustainable development of high-speed rail station based on node-place model--Taking the stations along Beijing-Shanghai high-speed rail as an example. *Urban Transp.* **2022**, *20*, 59–66+82. (In Chinese) [CrossRef]
39. Mao, J.; Li, C.; Li, C.; Xie, C. Study on the influencing factors of spatial development of station areas along high-speed railroads in Japan. *Railw. Transp. Econ.* **2020**, *42*, 68–74. [CrossRef]
40. He, J. A study on the accessibility of high-speed railroads in China: The Yangtze River Delta as an example. *Int. Urban Plan.* **2011**, *26*, 55–62. (In Chinese)
41. Wang, W. Research on Evaluation and Optimization Strategy of High-Speed Rail Station Area Based on Node-Place Model. Master's Thesis, Hebei University of Engineering, Handan, China, 2023. (In Chinese).
42. He, Q.; Liao, J. Evaluation model of multiplier effect on national economic development of highway network. *Highway* **2010**, *8*, 137–141. (In Chinese)
43. Liu, F.; Guo, Y.; Tang, Y.; Mao, L. Spatial reshaping and identity in the conservation and renewal of industrial heritage in railway station plots: The decline and rejuvenation of King's Cross in London. *Huazhong Archit.* **2021**, *39*, 104–109. (In Chinese) [CrossRef]

44. Reggiani, M. Urban Regeneration Strategies and Place Development in Contemporary Tokyo: The Case of Shibuya Station Area. *J. Place Manag. Dev.* **2022**, *15*, 40–54. [CrossRef]
45. Xiang, Q.; Lv, B. Planning guidance for the construction system of industrial park module space under the background of industry-city integration. *Planner* **2014**, *30*, 17–24. (In Chinese)

Disclaimer/Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.