

An Experimental Method of Station-City Integration Assessment

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Abstract

As the linchpins for transportation distribution, urban functional optimization, and sustainable development, railway hubs have crucial strategic significance. However, there is an urgently need for a specific framework in the collaborative exploration of station city integration and sustainable development in existed study. This study is committed to building an assessment system that combines station city integration with sustainable development, and explores the operational mechanism and optimization strategies of the interaction between railway hubs and urban space. Geographic information technology is utilized to constructs a scientifically appropriate assessment system, providing systematic technical supports for hub site location, functional configuration, and development intensity optimization, thereby improving hub transportation efficiency and coordinating the optimization of urban functions effectively.

1. Introduction

In the century of gradually severe global climate change, as the world's largest developing country China bears the dual task of reducing emissions and achieving sustainable development. Therefore, Chinese government proposed the "dual carbon" target in 2020, which is a principal strategy for addressing climate change. The targets is a necessary measure to mitigate global climate change, and it is also an important orientation for promoting high-quality economic development and energy structure transformation. National railway responded actively and promote the application and development of sustainable technologies.

With the advancement of regional integration, the scale of intercity passenger is expanding, and connections within urban agglomeration or metropolitan areas are being strengthened. Station-city integration provides a form of urban approach to create integrated transportation hubs, aiming to improve the relationship between railway stations and cities as well as to enhance the service quality and operation efficiency of comprehensive transportation hubs.

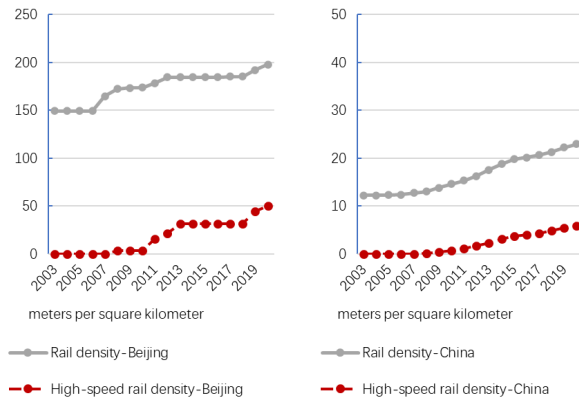
Chinese National railway has been striving to approach carbon peak and carbon neutrality through the emergence of the dual carbon target, various measures proposed optimizing national wide transportation structure and promoting sustainable operation. Both station-city integration and sustainable cities seek the sustainability of urban transportation and environment, in which their potential synergies are supposed to be considered during research and implementation process of railway planning, the role of station city integration in promoting sustainable development will be fully leveraged accordingly. A unified framework is constructed in this study to reconcile both station city integration and sustainable development.

As a core area of interaction between railway and city region, railway hubs not only assume the important function of transportation, but also affect the spatial structure and functional development of cities directly. With the fundamentals of dual-carbon target and regional coordinated development strategy, this study promotes the efficient connection between high-speed railroad hubs and main functional areas of cities by applying a classic Node-Place model to establish a station-city integration assessment system. Meanwhile, the experimental results could provide practical evidence for the green and sustainable transformation of cities, the construction of comprehensive regional transportation systems, and the coordinated development of urban and rural functions, supporting to fully leverage the role of railway hubs in promoting urban development and regional modernization.

This study measured the 15-minute cycling isochrones around each station as the pilot areas due to they are less affected by road and pedestrian networks, which is a more efficient method to confine the accessibility of railway stations(Nigro et al., 2019) As an infrastructure that can be used by most vehicles in the city, existing road is an appropriate network to analyze catchment area which displayed better heterogeneous characteristics(Gutiérrez et al., 2008). The value of 15-minute in this study is originated from 15-minute city, which emphasizes ensuring that residents can reach urban infrastructure within a 15-minute walking or cycling distance. This concept implementing in cities requires that infrastructure will be provided in close proximity to the city center, which could ensure that people are in an appropriate position in their socioeconomic status or age (Moreno et al., 2021).

The rationale for selecting Beijing, the capital of China, as the focus of our study research is based on two relevant aspects. Firstly, since the opening of high-speed rail in China, especially the first high-speed rail Beijing-Tianjin intercity railway with a designed speed of 350 kilometers per hour in August 2008, the

high-speed rail density in Beijing has been significantly higher than the national average level, as shown in Fig 1. Secondly, the various types of railway stations in Beijing offers foundation of experiment for study, allowing us to measure the level of station-city integration of different types of high-speed railway stations. As of the end of 2024, Beijing is the urban area in China with the most high-speed rail stations, including Beijing South Railway Station, which was first opened in 2008, and several newly reopened high-speed railway stations completed after 2016. The various high-speed railway lines depart from different railway stations in Beijing, presents a variety of patterns with the urban construction and public transportation levels in different areas of Beijing, providing a rich data for study on the spatial dependence relationship between railway stations and various urban built-up areas.



(a) The density of railway and high-speed railway routes within Beijing
(b) The density of railway and high-speed railway routes within China

Fig 1 The trends of national rail density and China from 2004 to 2020. Notes: The figures present an overview of the railway length in both Beijing and all over China regions, spanning the period from 2004 to 2020. (Davis et al., 2025)

This study contributes to the extant literature in two aspects. Firstly, the data of Beijing selected in this study validated a hypothesis that the railway station hub can integrate with the city and reach an equilibrium status by time after being connected to the HSR network. This finding not only verifies the promoting effect of urban planning and construction on station-city integration, but also emphasizes the universal applicability of transportation infrastructure positioning and urban planning methods in broader discussions.

Secondly, this study supplements to the extant literature on the analysis of railway stations and surrounding areas by introducing the concept of neighborhood planning. Through comparing delineation methods, we determined the 15-minute cycling isochrone as the pilot area of railway station, and socio-economic spatial distribution data are facilitated based on these ranges. The combination of this emerging concept and classic model provides unique insights and robust evidence for the ongoing discourse on the urban environmental impact of train stations.

The remaining section is structured as follows: Section 2 includes the context and description of HSR and Beijing, and proposes theoretical hypotheses of the impacts and influencing mechanism of urban development on the promotion of station-city integration. Section 3 introduces the data and methodology used in the delineation and empirical analysis of pilot area. Section 4 introduces the basis and process for indicator selection and weight determination, and demonstrates the analysis methods using geographic information technology. Section 5 analyzes the

experimental results of the study. Section 6 summarizes the conclusions of this study.

2. Study context

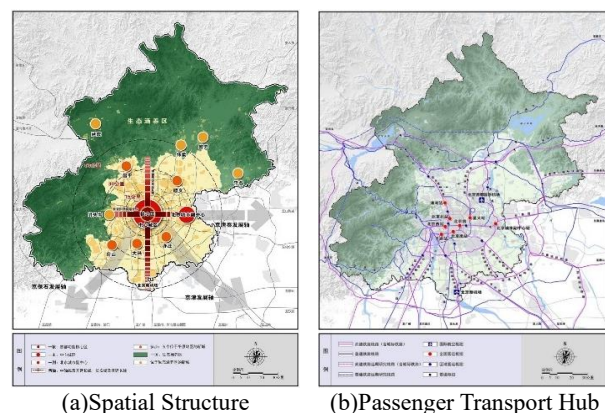
2.1 Development of High-Speed Rail in Beijing

Beijing, the capital of China, is the hub of China's railways network, playing a prominent role in the development of national economy and society. With the changing times, especially in the era of high-speed rail expansion, radial railway of Beijing became the largest railway hub in the country. The Medium-and Long-Term Railway Network Plan is the fundamental basis for promoting railway expansion and a guiding document for railway development. According to its tweaked version in 2008 and revised version in 2016, the development of high-speed railways in Beijing can be divided into two stages, accompanied by the process of railway network supporting the transformation and economic and social development of Beijing.

The partial construction of high-speed railways in China before 2008 began with the operation of the Qinhuangdao-Shenyang passenger dedicated line in 2003. In 2008, Beijing South Railway Station completed its renovation, which was regarded as the starting point of China's high-speed railway history. As a terminal station, Beijing-Tianjin intercity, the first high-speed railway line railway of Beijing, was put into operation at the same time. In October of the same year, the adjusted version of Medium-and Long-Term Railway Network Plan was approved and released by National Development and Reform Commission (NDRC). It planned "Four Vertical and Four Horizontal" passenger dedicated lines with intercity passenger transport systems in economically developed and densely populated areas, to meet the rapidly growing demand for passenger transportation and establish fast passenger transport channels between provincial capital cities and major cities. According to the planning and deployment of the "Four Vertical" passenger dedicated lines, Beijing-Shanghai high-speed railway and Beijing-Guangzhou high-speed railway, starting from Beijing, have been built and opened.

2.2 Regional division of Beijing

The "Beijing Master Plan (2016-2035)" divides the spatial structure of the Beijing into the Central Urban Area (Dongcheng, Xicheng, Chaoyang, Haidian, Fengtai, Shijingshan), Beijing Municipal Administrative Center and expansion area (Tongzhou), Pingyuan New City (Shunyi, Daxing, Yizhuang, Changping, Fangshan), and 5 All-Region Ecological Conservation District (Mentougou, Pinggu, Huairou, Miyun, Yanqing) as shown in Fig 2 (a). This study limits the Beijing Central Urban Area (BCUA) with an area of 1378km² as study area.



System
Fig 2 The Beijing Master Plan (2016-2035).

3. Pilot area and materials

This study focuses on the Beijing Railway Hub, the largest railway passenger transportation hub in China. According to Fig 2(b), the planning of the passenger hub system illustrated Beijing will have 8 national passenger hubs within its Central Urban Area. Xinghuo Railway Station is currently known as Beijing Chaoyang Railway Station, and Fengtai Railway Station is currently known as Beijing Railway Fengtai Station. Their new station building project have completed and put into use in 2020 and 2022.

Railway Station	Beijing North Railway Station	Beijing Chaoyang Railway Station	Beijing Fengtai Railway Station
Acronym	BN	BC	BF
	Beijing South Railway Station	Beijing West Railway Station	Qinghe Railway Station
	Beijing South Railway Station	Beijing West Railway Station	Beijing Railway Station
Acronym	BS	BW	QR
	BS	BW	QR

Table 1 Railway stations in Beijing Central Urban Area

There are currently 7 railway stations where high-speed passenger trains stop in BCUA as of the end of 2024. These railway stations were established along major railway lines according to increasing demand for passenger transit, have become significant hub stations connecting major urban agglomerations across the country.

3.1 Pilot areas

The study area is restricted to Beijing Central Urban Area as mentioned above. The region represents 7 railway stations and their surrounding polygonal areas illustrated in Fig 3 where are confined into 15-minute cycling isochrone around the stations.

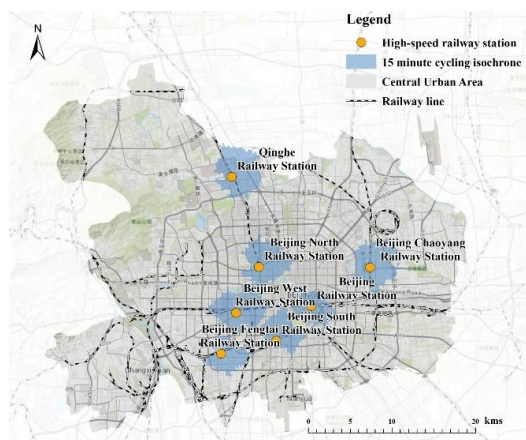


Fig 3 Station-city integration pilot areas and their distribution in Beijing Central Urban Area (BCUA).

Existing studies use the circular area around the train station as the surrounding area for study (Caset et al., 2018; Jeffrey et al., 2019; Nakamura, 2015; Vale, 2015), which expand the application of classic method of delineating the interaction area between transportation facilities and land use. For metropolitan area like Beijing, some areas cannot be reached directly, and the straight-line distance between two points usually differs greatly

from the actual walking distance. Therefore, a circular buffer zone with a specific radius used to represent the pedestrian catchment area may lead to overfitting of the analysis results.

Meanwhile, it is necessary to classify and consider the expansive area and diverse population distribution of Beijing, including its central urban area and its surrounding areas, as a centrally administered municipality. The pilot areas of 7 stations are influenced by different locations and natural environments, even though they are all located in the relatively densely populated Central Urban Area. Therefore, each station will be examined independently to analyze the degree of integration between the train stations and the city in this study.

Then we delineate the impact area of each station as thoroughly as possible, it is necessary to limit the length of the route, in order to avoid uncertain boundaries in the spatial dimension of the analysis areas (Vale et al., 2018). The pilot areas will overlap with each other if the length is too long, although this phenomenon does not mean that uncovered areas are not affected by those train stations. We selected the 15-minute isochrones of each station as the pilot area after several comparisons and comprehensive analysis. Fig 4 is a sample diagram of the pilot area (Beijing West Railway Station).

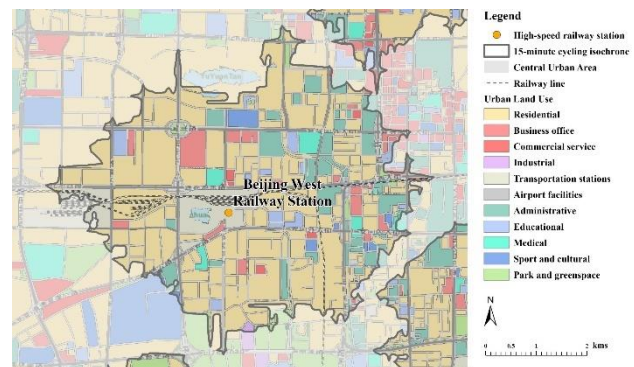


Fig 4 Integration Pilot Area of Beijing West Railway Station.

3.2 Pilot materials

Based on existed work, study on railway stations and their surroundings requires various traffic indicators and spatial data. Node indicators are constructed by various traffic modes, including national railway passenger flow, subway lines and stations, bus routes and stations, urban roads and highways, and their spatial geography information, which could be obtained from data released by official and map operator. On the contrary, the spatial distribution data required for measuring place indicators usually lacks official sources. This study processed and organized based on the measurement results published in previous studies.

The population spatial distribution data is obtained from the 100-m gridded population dataset generated from Seventh National Population Census in 2020 (Chen et al., 2024). Socioeconomic spatial distribution data comes from the results of the extrapolation of Beijing neighborhood socio-economic conditions of neighborhoods in traffic analysis zones scale measured from the sky and the street (Beijing_City_Lab, 2023). Urban land use data of BCUA is derived from essential urban land use categories remote sensing mapping data (Gong et al., 2020).

4. Methodology and procedure

This study explores the sustainable development path of station city integration, probing the effects of its intensive concept in carbon emission reduction. Meanwhile, this work aims to establish a comprehensive assessment indicator system to appraise the integration of High-Speed Rail hub stations and urban spaces comprehensively, and explore how Station City Integration reflects sustainable attributes.

Research procedure will be constructed to probe into the effect factors of the environmental friendliness in station city integration cases. It contains 3 steps: (1) we obtain railway passenger volume data of HSR stations in the Beijing Central Urban Area. Meanwhile, we collect multi domain data which include land use, facility distribution, urban public transit and road network and establish the station city integration index system based on the “node-place” model; (2) in terms of the connotation and orientation of station city integration, the entropy weight method will be applied to pinpoint the weights of sub-index of node and place. (3) due to the domain of current land use types around the High-Speed Rail stations, this study uses correlative spatial information technology to reveal the relationship between the spatial effect of station city integration and land use types. The detailed processes of these steps are as follows:

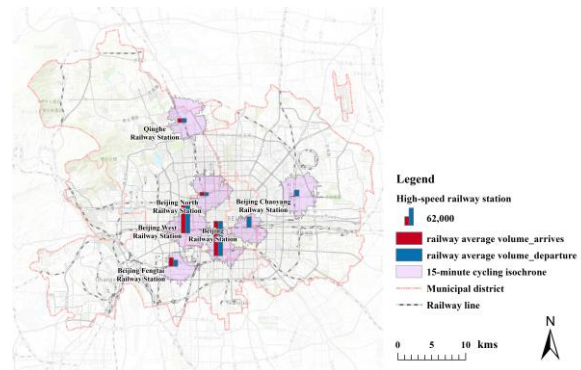
4.1 Selection of node index

Node index characterizes the transit activities and accessibility from High-Speed Rail hubs to other areas of the city. A variable combination analysis was conducted based on the situation in Beijing in this study, including national railway, urban rail transit, bus transit, and urban road traffic. Table 2 provides a recapitulative depictions and descriptive statistics of the selected indicators. Detailed depictions and selection procedures are below.

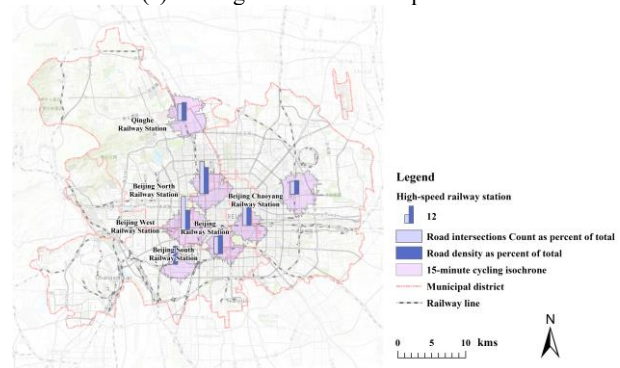
Type	Indicators	Unit
National railway accessibility	Number of high-speed train lines	Number per day
	Number of regular speed train lines	Number per day
	Passenger volume - departure	Volume per day
	Passenger volume - arrival	Volume per day
Urban rail transit accessibility	Number of urban rail transit stations within the pilot area	Number
	Number of urban rail transit lines within the pilot area	Number
	Number of subway stations accessible in 30 minutes	Number
Bus transit accessibility	Number of bus stops within the pilot area	Number
	Number of bus lines within the pilot area	Number
Urban road traffic accessibility	Length of motor lanes within the pilot area	km
	Density of urban roads within the pilot area	km/km ²
	Number of intersections within the pilot area	Number

Table 2 Selected exploratory indicators for node index

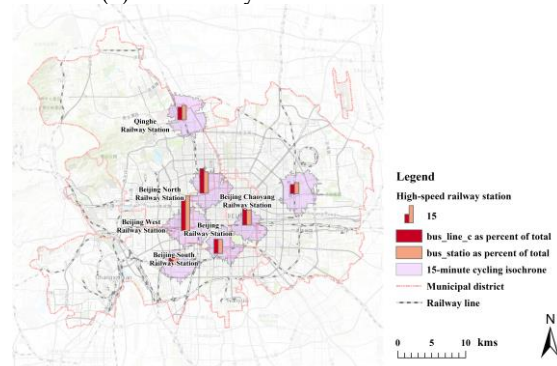
The variables of national railway accessibility, urban rail transit accessibility, and bus transit accessibility are positive indicators, reflected the usage frequency of public transportation, while a higher usage rate represents that carbon emissions decline. The total length of motor vehicle lanes and the density of urban roads within the pilot area are positive indicators, reflected the accessibility of motor vehicles in the urban area affected by stations. On the contrary, the number of intersections within the pilot area represents a variant of waiting time for driving, which is a negative indicator.



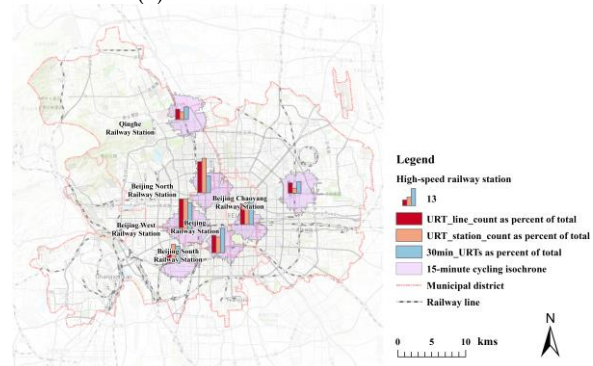
(a) Passenger arrivals and departures



(b) Road density and number of intersections



(c) Number of bus routes and stations



(d) Number of subway lines, stations, and stations accessible in 30 min

Fig 5 Node Index Analysis of Beijing Railway Station.

4.2 Selection of place index

The diversity and the proportion of land use are used to characterize the place dimension of those pilot area. Therefore, this study induces place indicators from three dimensions: land use diversity, land use mix, and socio-economic integration. The sub dimensions of land use diversity involve 8 indicators: park and greenspace land ratio, educational land ratio, residential land ratio, business office land ratio, commercial service land ratio, sport and cultural land ratio, administrative land ratio, and medical land ratio. The second sub-dimension is land use mix degree illustrated by land use entropy as the indicator. The calculation is as follows:

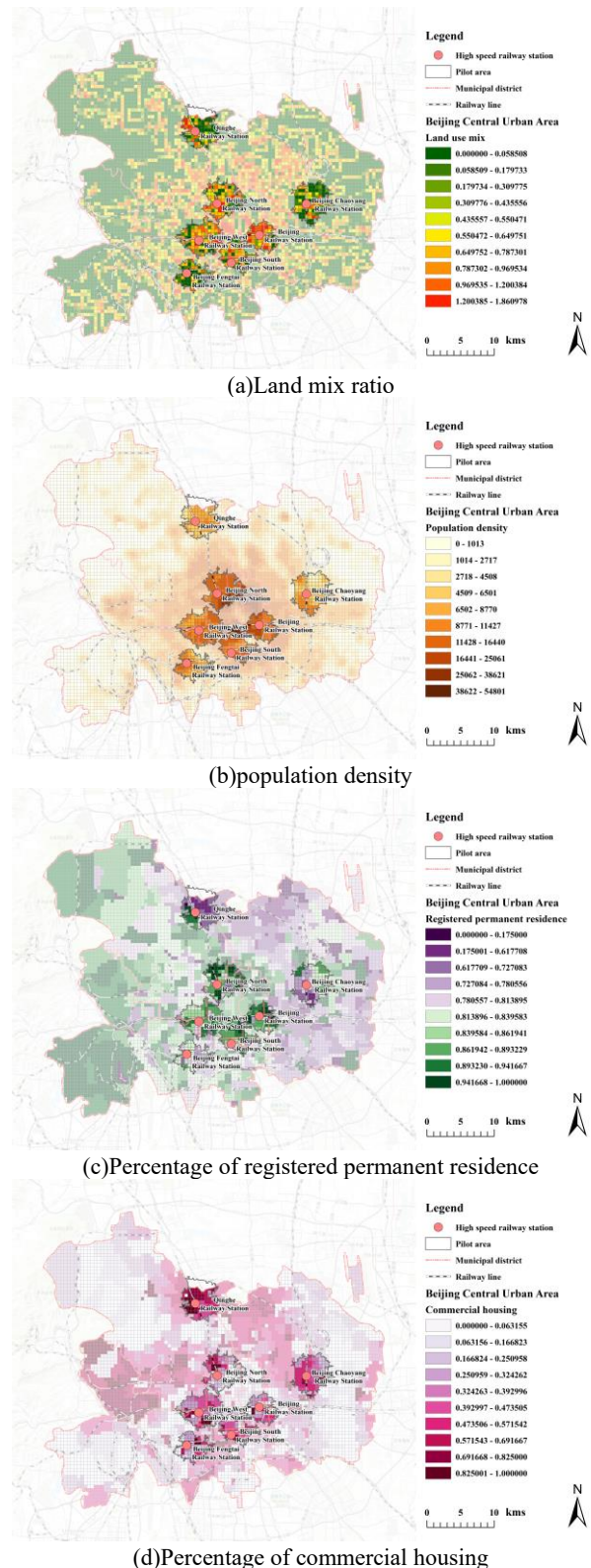
$$E = - \sum_{i=1}^m (P_i \times \ln P_i) \quad (1)$$

where P_i is the proportion of i_{th} land use types in each pilot area, and m is the number of land use types.

Socio-economic integration of those pilot area around railway stations will be measured by the number of residents. Furthermore, there are 4 indicators will be contained: average household income, per capita building area, percentage of commercial housing, percentage of registered permanent residence, and floor area ratio. provides a recapitulative depictions and descriptive statistics of the selected indicators. Detailed depictions and selection procedures are below.

Type	Indicators	Unit
Land use mix	Land use entropy	-
Land use diversity	Park and greenspace land ratio	%
	Educational land ratio	%
	Residential land ratio	%
	Business office land ratio	%
	Commercial service land ratio	%
	Sport and cultural land ratio	%
	Administrative land ratio	%
	Medical land ratio	%
Socio-economic integration	Number of residents	<i>pers/km²</i>
	Average household income	10000CNY/year
	Per capita building area	<i>m²</i>
	Percentage of commercial housing	%
	Percentage of registered permanent residence	%
	Floor area ratio	-

Table 3 Selected exploratory indicators for place index



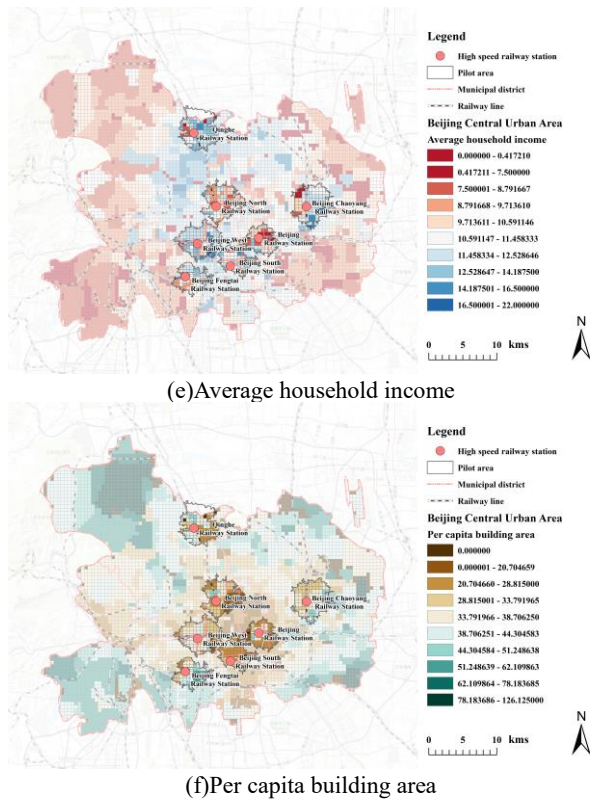


Fig 6 Place Index Analysis of Beijing Railway Station.

4.3 Weights determination

Indicators will be normalized before determining the weight. Among all the indicators of node-place, railway accessibility, urban rail transit accessibility, bus transit accessibility, urban road traffic accessibility (exclude number of intersections within the pilot area), land use mix, and land use diversity are positive indicators are rescaled to have a minimum value of 0 and a maximum of 1 using the formula:

$$X_p = \frac{X - \text{Min}(X)}{\text{Max}(X) - \text{Min}(X)} \quad (2)$$

The number of intersections within the pilot area is a negative indicator be rescaled to have a minimum value of 0 and a maximum of 1 using the formula: maximum of 1 using the formula:

$$X_n = \frac{\text{Max}(X) - X}{\text{Max}(X) - \text{Min}(X)} \quad (3)$$

where X_p , X_n are the scaled indicators, $\text{Max}(X)$ is the maximum value of indicator X , and $\text{Min}(X)$ is the minimum value of index X .

The degree of socio-economic integration are intermediate indicators are supposed to rescaled to have a minimum value of 0 and a maximum of 1 using the formula:

$$M = \max\{|Y - Y_{\text{expected}}|\}, Y_i = 1 - \frac{|Y - Y_{\text{expected}}|}{M} \quad (4)$$

where Y_i is the scaled indicator, and Y_{expected} is the expected value of index Y whose value is derived from the socio-economic average index of BCUA, which will be calculated in accordance with methods in Table 4 as follow.

Indicators	Calculation Method	Expected Value
<i>Permanent population in BCUA</i>		
Number of residents	<i>Area of BCUA</i>	7974.30
	$= \frac{10988587 \text{ pers}}{1378 \text{ km}^2}$	
	$= 7974.30 \text{ pers/km}^2$	
Average household income	<i>Per capita disposable income of E</i>	92464
Per capita building area	$= 92464 \text{ CNY}$	
Percentage of commercial housing	$33.41 \text{ m}^2/\text{pers}$	33.41
Percentage of households with hukou	<i>Number of completed commercial housing</i>	41.5%
	<i>Number of current urban residents</i>	
	$= 41.5\%$	
Floor area ratio	<i>Registered residence population</i>	65.55%
	<i>Permanent resident population of Beijing</i>	
	$= \frac{1431.2 \text{ million people}}{2183.2 \text{ million people}}$	
	$= 65.55\%$	
	<i>Floor area ratio of urbanization</i>	1.0746
	$= 1.0746$	

Table 4 Expected value and calculation method of social and economic integration indicators

Entropy weight method will be used to determine the weights of sub indicators for node-place after the normalization. The calculation results are as follows.

Category	Type	Indicators	Weight
Node	National railway accessibility	Number of high-speed train lines	0.058
		Number of regular speed train lines	0.055
		Passenger volume - departure	0.064
		Passenger volume - arrival	0.061
		Number of urban rail transit stations within pilot area	0.030
	Urban rail transit accessibility	Number of urban rail transit lines within pilot area	0.049
		Number of subway stations accessible in 30 minutes	0.033
		Number of bus stops within the pilot area	0.039
	Bus transit accessibility	Number of bus lines within the pilot area	0.047
		Length of motor lanes within the pilot area	0.038
Place	Urban road traffic accessibility	Density of urban roads within the pilot area	0.022
		Number of intersections within the pilot area	0.040
		Land use mix	0.036
	Land use diversity	Land use entropy	0.044
		Park and greenspace land ratio	0.043
		Educational land ratio	0.027
		Residential land ratio	0.020
		Business office land ratio	0.023
		Commercial service land ratio	0.023

Socio-economic integration	Sport and cultural land ratio	0.033
	Administrative land ratio	0.028
	Medical land ratio	0.027
	Number of residents	0.032
	Average household income	0.035
	Per capita building area	0.017
	Percentage of commercial housing	0.019
	Percentage of registered permanent residence	0.058
	Floor area ratio	0.020

Table 5 Weight of node-place indicators

5. Results

The normalized indicators were linearly weighted with their weights to obtain the node-place value i ($0 < i < 1$) for the 7 railway hubs in the central urban area of Beijing.

Indicators	BN	BC	BF	BS	BW	QR	BR
Number of high-speed train lines	0.004	0.012	0.000	0.058	0.027	0.014	0.001
Number of regular speed train lines	0.005	0.000	0.055	0.000	0.041	0.011	0.044
Passenger volume - departure	0.000	0.006	0.006	0.064	0.050	0.002	0.015
Passenger volume - arrival	0.000	0.005	0.010	0.061	0.047	0.001	0.014
Number of urban rail transit stations within pilot area	0.030	0.000	0.014	0.011	0.027	0.003	0.018
Number of urban rail transit lines within pilot area	0.049	0.000	0.008	0.016	0.049	0.000	0.025
Number of subway stations accessible in 30 minutes	0.011	0.000	0.012	0.027	0.033	0.003	0.028
Number of bus stops within the pilot area	0.019	0.004	0.000	0.009	0.039	0.009	0.011
Number of bus lines within the pilot area	0.033	0.000	0.002	0.011	0.047	0.008	0.017
Length of motor lanes within the pilot area	0.022	0.010	0.000	0.004	0.038	0.008	0.010
Density of urban roads within the pilot area	0.022	0.000	0.008	0.020	0.013	0.008	0.013
Number of intersections within the pilot area	0.037	0.004	0.000	0.011	0.040	0.010	0.014
Land use entropy	0.024	0.000	0.001	0.023	0.023	0.008	0.036
Park and greenspace land ratio	0.004	0.044	0.017	0.011	0.000	0.013	0.006
Educational land ratio	0.043	0.000	0.008	0.011	0.004	0.010	0.013
Residential land ratio	0.008	0.000	0.019	0.017	0.014	0.027	0.005

Business office land ratio	0.014	0.000	0.010	0.007	0.014	0.011	0.020
Commercial service land ratio	0.023	0.007	0.009	0.018	0.011	0.010	0.000
Sport and cultural land ratio	0.022	0.033	0.002	0.000	0.022	0.010	0.027
Administrative land ratio	0.012	0.006	0.008	0.016	0.027	0.000	0.028
Medical land ratio	0.027	0.011	0.004	0.013	0.016	0.000	0.020
Number of residents	0.010	0.000	0.003	0.006	0.007	0.001	0.008
Average household income	0.018	0.011	0.016	0.008	0.002	0.000	0.028
Per capita building area	0.012	0.010	0.000	0.012	0.015	0.014	0.008
Percentage of commercial housing	0.012	0.016	0.008	0.014	0.011	0.000	0.007
Percentage of registered permanent residence	0.000	0.022	0.016	0.003	0.006	0.046	0.002
Floor area ratio	0.000	0.018	0.009	0.008	0.016	0.009	0.016

Table 6 Node-place value of railway hubs in BCUA

The node-place score I ($0 < I < 100$) will be obtained by multiplying value with 100, as illustrated in Table 5.

Station	BN	BC	BF
Node	23.3	4.1	11.5
Place	23.0	17.9	13.0

Station	BS	BW	QR	BR
Node	29.1	45.1	7.8	20.9
Place	16.6	18.8	15.8	22.4

Table 7 Node-place score of railway hubs in BCUA

As shown in Fig 7, the scatter diagram depicts the relationship between node indicators and place indicators of 7 railway hubs.

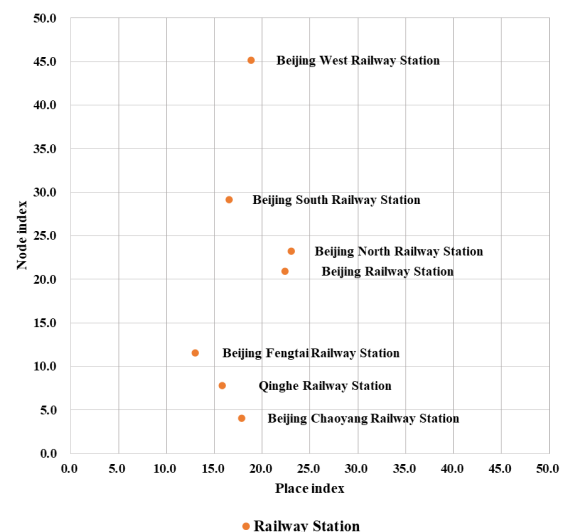


Fig 7 Integration assessment of station-city in Beijing Central Urban Area.

6. Conclusion

Among the 7 railway stations in BCUA, Qinghe and Beijing Fengtai are dependent hubs, which is mainly related to their completion time of reconstruction in the recent past; Qinghe originally opened in 1906, train from Beijing heading northwest to the cities in Hebei Province and Inner Mongolia Autonomous Region stops, the current station was rebuilt and opened on December 30, 2019 to accommodate high-speed rail services. Beijing Fengtai is a railway station reopened for operation and connected to the high-speed rail network in 2022 after more than 4 years of construction, located in Fengtai where promising developmental tendencies evinced. It is served by high-speed railways such as Beijing Guangzhou high-speed railway passenger transportation, having a great potential as it will be the starting point of Beijing–Shangqiu high-speed railway which will trigger a significant increase in passenger flow.

Beijing South, Beijing North and Beijing are balanced hubs. These 3 stations have a long history of intercity passenger transit, maintained a relative balance with their surrounding urban areas in the process of Beijing urban development. Beijing Railway Station is the longest operating railway station in the BCUA, and the station building has been recognized as a cultural relic by the National and Beijing Municipality. Urban renewal projects in Beijing Station and surrounding areas have been promoted by China railway and relevant departments of Beijing in recent years, aiming to restore the original appearance and improve the urban spatial environment, while optimizing transportation connections and transfers.

Beijing West is an unsustainable node. It is a station planned and constructed to meet the dramatic increase in intercity traffic at 1990s, and continuously expanded its facilities and capacity through multiple renovation projects. The station is located on the Fengtai side of the boundary between Haidian District and Fengtai District, adjacent to an urban expressway. The unbalance of urban construction and the barrier of Lianhuachi Park on the southwest side, result in a relatively small place index.

Beijing Chaoyang is an unsustainable place that takes a short time of operating high-speed railway passenger transport business. Formerly known as Xinghuo, Beijing Chaoyang began operation on 22 January 2021, turning to terminus of the Beijing–Shenyang high-speed railway, which is a part of is a section of the Beijing–Harbin high-speed railway. The adjacent subway station is the middle station of Beijing Subway Line 3, which has undergone protracted changes in the different period of Beijing planning and eventually opened on December 15, 2024.

Type	Railway Station	Access to HSR network
Stress	None	-
Dependency	Qinghe	2019/12/30
	Beijing	2022/6/20
	Fengtai	2019/12/30
Accessibility (Balanced)	Beijing North	2019/12/30
	Beijing South	2008/8/1
Unsustainable node	Beijing	-
	Beijing West	2019/9/26
Unsustainable place	Beijing Chaoyang	2021/1/22

Table 8 Spatial types of railway hubs in BCUA

Appendix

Appendix 1 15-minute isochrone delineation method based on road network

The 15-minute pilot area of each railway stations were delineated by an application programming interface through Isochrone Playground of *Mapbox*, an online maps provider. Before performing aforementioned step, the latitude and longitude of railway stations as listed in has been obtained through web mapping platform.

Name of Railway station	Longitude (East)	Latitude (North)
Beijing North Railway Station	116.35	39.94
Beijing Chaoyang Railway Station	116.50	39.94
Beijing Fengtai Railway Station	116.30	39.85
Beijing South Railway Station	116.37	39.86
Beijing West Railway Station	116.32	39.89
Beijing Railway Station	116.42	39.90
Qinghe Railway Station	116.31	40.04

Table 9 Longitude and Latitude of railway stations

Appendix 2 Social and economic indicators and their sources

Social and economic indicators	Literature source
Permanent population in BCUA	Beijing Seventh National Population Census Bulletin (No. 2)
Area of BCUA	Beijing Master Plan (2016-2035)
Per capita disposable income of Beijing urban residents	2024 data from Survey Office of the National Bureau of Statistics in Beijing
Per capita building area	China Census Yearbook (2020)
Percentage of commercial housing	China Housing Stock Calculation Report (2024) (Ren et al)
Registered residence population of Beijing	Beijing Statistical Yearbook (2024)
Permanent resident population of Beijing	Statistical Bulletin on National Economic and Social Development of Beijing (2024)

Appendix 3 Calculation method for expected value of FAR

Floor area ratio (FAR) is the ratio of a zone's total floor area (gross floor area) to the area of the zone, written as a

$$FAR = \frac{\text{Gross Floor Area}}{\text{Plot Area}} \quad (5)$$

The expected value is represented by plot ratio in BCUA with a total floor area of 1096.08km^2 , estimated from Multi-Attribute Building Dataset(Zhang et al., 2025) of Beijing..

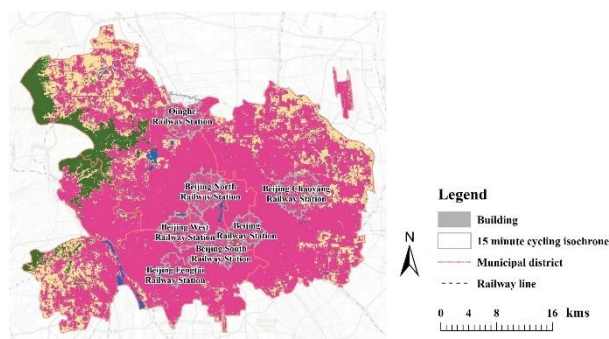


Fig 8 Land Cover of BCUA.

The built-up area of BCUA is 1020.02km^2 , derived the area of impermeable surface in China Land Cover Dataset(Yang et al., 2024)as shown in Fig 8. The calculated floor area ratio of BCUA built-up area is 1.0746 as the expected value.

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