Coupling Coordination Analysis of New Urbanization and Urban Transportation in Zhejiang Province

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Abstract. At present, there are relatively few studies on the coupling coordination analysis of new urbanization and urban transportation. This paper takes 11 preface-level cities in Zhejiang Province as the research object and analyses the new urbanization and urban transportation development status of each city in 2010, 2015, and 2020 through the construction of the index system. In addition, the paper uses the entropy method and the coupling coordination model to evaluate their coupling coordination relationship. The results show that: (1) The new urbanization has developed from Hangzhou as the single core (2010) to the pattern of Hangzhou, Ningbo, and Zhoushan as the dual-core + the "Quzhou-Lishui-Wenzhou-Taizhou" high-value belt in the south (2020), which spatially shows a trend of high in the north and low in the south. (2) Urban transportation has always centralized in Zhoushan as the single core, with the overall distribution high in the north and low in the south. (3) At the three time periods, the coordination degree of new urbanization and urban transportation in all preference-level cities is almost 0.4 and above, which exceeds the level of antagonistic equilibrium (0-0.2), which is divided into four categories, namely, low, medium, high, and coordinated equilibrium levels. Most of the preface-level cities are in medium and high equilibrium. Hangzhou (0.707) and Zhoushan (0.800) are high-value representations of coordinated equilibrium, while Jinhua (0.473) and Lishui (0.439) are typically low in the value of low-grade equilibrium. (4) The development of new urbanization and urban transportation as well as their coupling coordination relationship are related to urban positioning and geographical location. The research has a constructive role in evaluating the new urbanization and urban transportation of the cities in Zhejiang, which also makes a reference on how to improve the quality of coordination based on the status quo of coupling coordination and the positioning of urban development.

Keywords: Zhejiang Province; New Urbanization; Urban Transportation; Coupling Coordination Analysis.

1. Introduction

Since the reform and opening up, remarkable achievements have been seen in China's urbanization, whose rate has climbed from 17.9% in 1978 to 63.89% in 2020. National New Urbanization Planning (2014-2016) points out that there are some problems in China's urbanization, such as urban-rural dual economic structure, extensive land expansion, lagging urban management service capacity, urban diseases, and so on. In this context, the country has incorporated new urbanization into the national development plan promptly, emphasizing the coordinated development of urban and rural areas through an efficient, intensive, and balanced development paradigm. The 18th National Congress of the Communist Party of China referred to the new urbanization with people as the core to improve the general improvement of urban functions and sustainable development. Collaborating with different urban development units through a complete transportation network is the only way to slow down economic development and enhance the quality of new urbanization. In 2019, the Outline for the Construction of National Strength in Transportation issued by the Central Committee of the Communist Party of China and the State Council emphasized that building a national strength in transportation should change from pursuing the speed of development to pursuing its quality and the subdivided transportation modes should transform from relatively independent development to a more coordinated and integrated mode. Zhejiang Province, as an important cradle of new urbanization in China, has an urbanization rate of 72.17% in 2020, ranking first in China. At the same time, it highlights the leading role of the railway in the planning and construction of urban transportation, which forms an urbanization pattern of metropolitan areas, small and medium-sized cities, and characteristic towns, providing vital references for the development of new urbanization in China.

On the one hand, there is a mutual promotion mechanism between new urbanization and urban transportation. First of all, urban transportation ecological construction can promote the intensive use of urban land. Compared with the traditional urbanization relying on land expansion, the construction of urban transportation ecology is very crucial for cities to achieve higher quality spatial expansion. Yu (2015) who analyzed the coordination degree between urban spatial expansion and transportation in Zhengzhou believed that good transportation facilities construction is of great significance for realizing high-quality urban spatial expansion, while the lagging infrastructure construction will hinder the overall development of the city. Zhou and Zeng (2016) studied the role of transportation infrastructure in urbanization in central China. In the traditional urban development mode, the role of land expansion in promoting urbanization is reduced after considering spatial factors, while the construction of transportation infrastructure and urbanization shows a long-term positive relationship, which better plays the spatial spillover effect combined with intensive land use. Secondly, improving urban transportation infrastructure can effectively boost the flow of population, economy, and other factors within cities and inter-cities, thus promoting the development of new urbanization. Cheng et al. (2013) found that in relatively developed counties in Shandong Province, comprehensive transportation accessibility and economic development showed a high level of coordination in time and space. Finally, the construction of urban transportation can promote the overall planning of urban and rural areas. Li et al. (2017) pointed out that urban-rural connection is the fundamental feature. Meanwhile, the improved conditions can significantly strengthen the communication between urban and rural areas in production, consumption, and culture. Luo and Peng (2016) found that transportation infrastructure can positively improve the improvement of urban-rural income equity in various provinces and regions.

On the other hand, incomplete urban transportation construction will limit the process of new urbanization. At the beginning of the 21st century, the imperfect transportation in some big cities in China not only leads to economic losses and waste of land resources but also causes serious urban environmental pollution such as waste gas pollution and noise pollution (Wei, 2001). Under the background of new urbanization, perfect urban transportation construction can alleviate such problems to a certain extent. Ding et al. (2021) put forward the suggestion that urban transportation construction should match the needs of urban development and considered that relatively backward transportation conditions would put a drag on urban development, while overly advanced transportation construction would lead to economic pressure and waste of resources. New urbanization emphasizes sustainable green development and intercity communication, which corresponds to the key development of public transportation, emphasis on the intensive use of resources, and the key construction of intercity transportation network (Ji & Dou, 2016).

At present, there are abundant research objects for coupling coordination of new urbanization, such as scientific and technological innovation, economic and financial development, ecological civilization construction, basic education resource allocation, cultural tourism industry, industrial cluster, integration of production and city, etc. (He, Yan & Guan, 2020). However, most of them focus on the relatively macro research scale, such as the Yangtze River Delta urban agglomeration, the national agricultural areas, etc, while seldom study from the prefecture-level city perspective. Currently, few studies have established a relatively complete index system to evaluate the coupling coordination relationship between urban transportation and new urbanization in Zhejiang Province. Therefore, this study constructs an evaluation index system for new urbanization and urban transportation development based on scientific and objective principles. Besides, it studies the coupling degree and status of urban transportation development and new urbanization in 11 prefecture-level cities in Zhejiang Province by entropy method and coupling coordination model, which provides evaluation reference and evidence for the coordinated development of new urbanization and urban transportation in Zhejiang and even the whole country.

2. Study Area and Method

2.1 Study Area

Zhejiang Province is located in the southern Yangtze River Delta (118 01 '-123 10' E, 27 02 '-31 11' N), which is one of the provinces with the smallest gaps in economic development in China. It has two sub-provincial cities, Hangzhou and Ningbo, and nine prefecture-level cities, including Wenzhou and Huzhou. During the Thirteenth Five-Year Plan period, its urbanization rate of permanent residents rose to 72.2%, which was 8 percent higher than the national average urbanization rate; In the past five years, the accumulated investment in comprehensive transportation has reached 1.4 trillion yuan (the first in China), leading the country in new urbanization and transportation construction.

2.2 Research Methodology

2.2.1 Entropy Method

The entropy method is an objective weighting method based on the entropy of index information, which can avoid subjective prejudice of subjective weighting method and information loss of principal component analysis. The calculation steps are as follows:

First, the data is dimensionless:

$$X_{ij}^{'} = \begin{cases} \frac{X_{ij}-min\{X_j\}}{max\{X_j\}-min\{X_j\}} & positive\ index \\ \frac{max\{X_j\}-X_{ij}}{max\{X_j\}-min\{X_j\}} & negative\ index \end{cases} \tag{1}$$

In the formula, $X_{ij}^{'}$ is the standard value, X_{ij} is the jth original value of the index (j=1, 2, …, n) of the ith city (i=1, 2, …, m).

Secondly, the index weight is determined:

$$w_j = \frac{1-e_j}{\sum_{j=1}^{n}(1-e_j)} \tag{2}$$

Among them,

$$e_j = -\frac{1}{\ln m}\sum_{i=1}^{m}(Y_{ij} \times \ln Y_{ij}) \tag{3}$$

$$Y_{ij} = \frac{X_{ij}^{'}}{\sum_{i=1}^{m} X_{ij}^{'}} \tag{4}$$

In the formula, w_j is the weight of the jth index and e_j is the entropy value of the jth index.

Thirdly, the comprehensive scores of each city are calculated by using the weighted summation method:

$$S_i = \sum_{j=1}^{n}(w_j \times X_{ij}^{'}) \tag{5}$$

Finally, the scores of new urbanization and urban transportation construction are divided into five grades, including low, relatively low, medium, high, and relatively high by using the Jenks method, which is the most appropriate method for grouping similar values and is commonly used for grading small sample data.

2.2.2 Coupling Coordination Model

The coupling coordination model is often used to analyze the coordination development between two or more systems, which can reflect the degree of interdependence and restriction between systems and the quality of coordination. This study focuses on the two systems of new urbanization and urban

transportation. After the score is obtained by using the entropy method, the coupling coordination model is introduced for subsequent calculation.

The coupling degree calculation model is as follows:

$$C = 2\left(\frac{SJ}{(S+J)^2}\right)^{\frac{1}{2}} \quad (6)$$

In the formula, $S$and $J$are the scores of new urbanization and urban transportation construction respectively, while C is the coupling degree.

The coordination degree calculation model is as follows:

$$D = (C \times T)^{\frac{1}{2}} \quad (7)$$

$$\text{Among them: } T = \alpha S + \beta J \quad (8)$$

T is the summation of new urbanization and urban transportation construction, α and β are the weights of new urbanization score and urban transportation construction score respectively, which are both set to 0.5 according to the existing research, that is, they are equally important.

This paper focuses on the coupling coordination degree between new urbanization and urban transportation development, fully considers the mathematical meaning, and combines the grading results of existing coupling coordination degrees such as those from Sun Yu et al. (2020). This study establishes the grading rules of coordination degree D according to data distribution as shown in Table 1.

Table 1. Division Standard of Balanced Development

D Value Interval	Balanced Development
0.0 < D ≤ 0.2	Antagonistic Equilibrium
0.2 < D ≤ 0.5	Low Level Equilibrium
0.5 < D ≤ 0.6	Medium Equilibrium
0.6 < D ≤ 0.7	High Equilibrium
0.7 < D ≤ 1.0	Coordinated Equilibrium

2.3 Data Sources and Processing

The data of this study mainly come from the China Statistical Yearbook, China Urban Construction Statistical Yearbook, Zhejiang Natural Resources and Environment Statistical Yearbook, statistical yearbooks of various cities, and statistical bulletin of national economic and social development in 2010, 2015, and 2020. Because there are differences among different statistical data for some indicators, the principle of the unified source is followed in data statistics, that is, the data of the same indicator is selected from the same statistical data as much as possible.

3. Index System Construction

New urbanization is people-oriented and pays attention to promoting economic, social, and ecological development in a sustainable manner. Therefore, the construction of a new urbanization evaluation index system needs to comprehensively consider population, economic and social urbanization, and ecological civilization. The evaluation of urban transportation should take into account the infrastructure construction and its development status, in which the infrastructure construction can be reflected by road construction and transportation ownership, while the development status is reflected by passenger and freight volume. Based on the principles of science, comprehensiveness, and data availability, this paper makes full reference to the research results of Wang (2014), Peng et al. (2014), Cai et al. (2021), Zhang Hu et al. (2022), and other scholars. A set of index systems (Table 2) are established for new urbanization and urban transportation construction. The new urbanization is divided into four first-level indicators, including population urbanization, economic urbanization, social urbanization, and ecological civilization. Meanwhile, urban transportation construction is divided into two first-level indicators, that is, road network construction and urban public transportation. Each first-level indicator contains several secondary indicators, which are highly explanatory.

Table 2. Evaluation System of New Urbanization and Urban Transportation Construction

Target Layer	First-Level Index	Secondary Index	Attribute	Unit
New Urbanization	Population Urbanization (X_1)	Urbanization Rate of Resident Population (X_{11})	Positive	%
		Population Density (X_{12})	Positive	People/km^2
		Per 10,000 Students in Colleges (X_{13})	Positive	People
	Economic Urbanization (X_2)	Per Capita GDP (X_{21})	Positive	RMB
		Electricity Consumption Per Unit GDP (X_{22})	Negative	KWh/RMB
		Ratio of Added Value of Secondary Industry to GDP (X_{23})	Positive	%
		Ratio of Added Value of Tertiary Industry to GDP (X_{24})	Positive	%
		Per Capita Disposable Income of Urban Residents (X_{25})	Positive	RMB
	Social urbanization (X_3)	Per Capita Expenditure on Education (X_{31})	Positive	RMB
		Per Capita Expenditure on Science and Technology (X_{32})	Positive	RMB
		Number of Patents Granted (X_{33})	Positive	Piece
		Public Library Collections Per Capita (X_{34})	Positive	Volume
		Per Capita Income Ratio of Urban and Rural Residents (X_{35})	Negative	Dimensionless
		Per Capita Consumption Ratio of Urban and Rural Residents (X_{36})	Negative	Dimensionless
	Ecological Civilization (X_4)	Per Capita Green Area in Parks (X_{41})	Positive	㎡
		Green Coverage Rate of Built-up Area (X_{42})	Positive	%
		Excellent Rate of Urban Air quality (X_{43})	Positive	%
		Municipal Sewage Treatment Rate (X_{44})	Positive	%
Urban Transportation Construction	Road Network Construction (Y_1)	Per Capita Urban Road Area (Y_{11})	Positive	㎡
		Proportion of Expressways (Y_{12})	Positive	%
		Regional Highway Density (Y_{13})	Positive	Km/km^2
	Urban Public Transport (Y_2)	Public Buses (Electric Vehicles) Per 10,000 People (Y_{21})	Positive	Vehicles
		Number of Taxis Per 10,000 People (Y_{22})	Positive	Vehicles
		Per Capita Highway Passenger traffic (Y_{23})	Positive	Person-to-person
		Tonnage of Waterway Freight Per Capita (Y_{24})	Positive	Tons Per Capita
		Car Ownership Per 10,000 People (Y_{25})	Positive	Vehicles
		Tonnage of Road Freight Per Capita (Y_{26})	Positive	Tons Per Capita

4. Result Analysis

4.1 Evaluation of the New Urbanization Development in Zhejiang Province

It can be seen from Figure 1 that the new urbanization in Zhejiang Province has flourished from Hangzhou. In 2010, the new urbanization in the province was still a single-core pattern; In the following ten years, it gradually expanded from northeast to south. By 2020, it has developed into a

dual-core basin pattern of Hangzhou-Ningbo and Zhoushan. The development of new urbanization in Hangzhou is always the first, while Ningbo and Zhoushan gradually rise as the second cores. In addition, "Quzhou-Lishui-Wenzhou-Taizhou" in the south forms a high-value belt of basin step by step horizontally to a relatively high development of Jinhua, and "Huzhou-Jiaxing-Shaoxing" develops stably, among which Shaoxing always leads relatively.

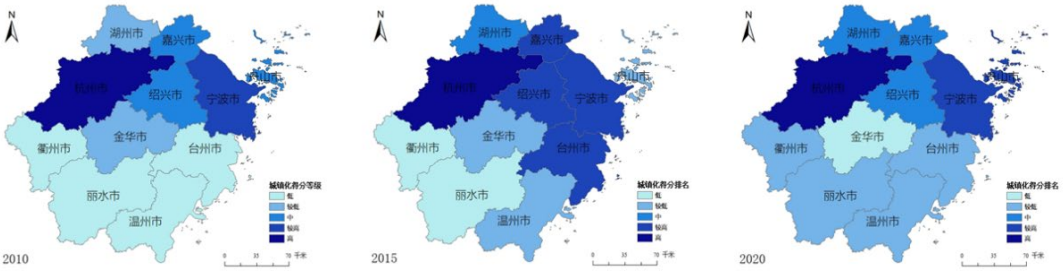


Figure 1. Temporal and Spatial Pattern of New Urbanization Development in Prefecture-Level Cities of Zhejiang Province from 2010 to 2020

Figure 2 shows the contribution rate of the first-level indicators of new urbanization, in which the correlation between social urbanization and new urbanization is high. Meanwhile, the development of new urbanization in Hangzhou, Ningbo, and Zhoushan is high, with their contribution rate of social urbanization all exceeding 0.35. New urbanization is deeply bound with economic development, financial improvement, and people's livelihood construction. Cities promote the increase of residents' income through efficient and coordinated development mode, provide sufficient sources of fiscal expenditure, and enhance the development of social urbanization.

Among the four first-level indicators, the contribution rate of population urbanization is the lowest, which continues to decline as a whole. Hangzhou has dropped from 0.27 in 2010 to less than 0.25 in 2020. On the one hand, Zhejiang Province has gradually transitioned from early urbanization to new urbanization, because the demographic dividends where rural young and middle-aged laborers migrated to cities to engage in non-agricultural industries have passed; On the other hand, population urbanization includes "the number of students in higher education per 10,000 people", interconnection between population urbanization and higher education may be the direct reason for the relatively low development of population urbanization.

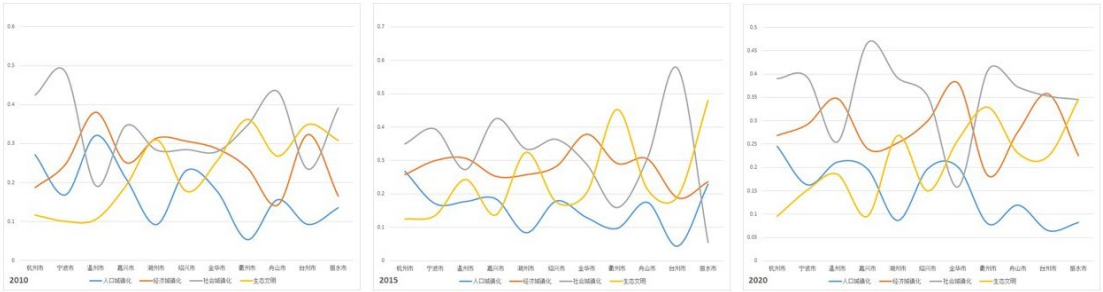


Figure 2. Contribution Rate of First-Level Indicators of New Urbanization in Prefecture-Level Cities of Zhejiang Province from 2010 to 2020

4.2 Urban Transportation Construction

The spatial distribution of urban transportation construction scores in prefecture-level cities in Zhejiang is similar to that of new urbanization, showing a distribution pattern of high in the north and low in the south with Zhoushan as the single core (Figure 3). Zhoushan in the northeast keeps a high construction score at three time periods, while Lishui in the south always has a low score. Hangzhou, Ningbo, and Jiaxing in the north have similar rankings, presenting a steady and then declining trend, while Quzhou and Taizhou in the middle have achieved an increase in construction scores in ten years.

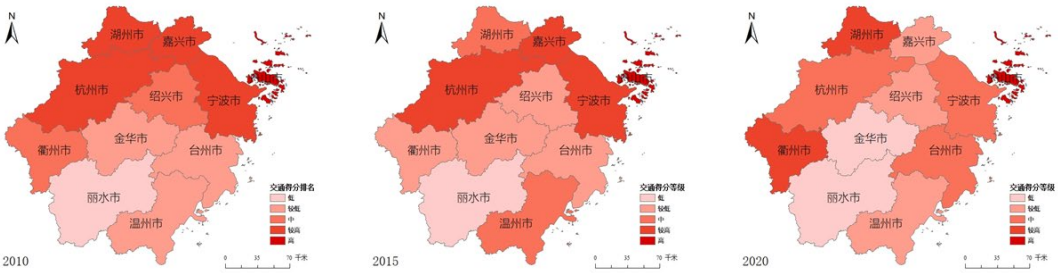


Figure 3. Spatial Pattern of Urban Transportation Construction and Development in Zhejiang Province from 2010 to 2020

From the contribution rate of first-level indicators (Figure 4), it is a common phenomenon that urban public transport indicators dominate between road network construction level and urban public transport. Among 11 prefecture-level cities, only Jiaxing keeps the contribution rate of road network construction level exceeding that of urban public transport (reaching 0.59: 0.41 in 2020). The secondary index of research and design makes the road network construction comprehensively consider the construction degree of road length and density, while the urban public transportation index comprehensively considers the traffic vehicle quantity, passenger transport, and freight transport status. Besides, there is an inherent interactive mechanism between the two first-level indexes. The road network is the hardware infrastructure of urban transportation, and its construction degree and science-based identity affect the transportation development of the whole city. On the one hand, urban public transportation shows the development of urban roads. On the other hand, it transmits the development demand through its coordination with road network construction. Wang (2015) believes that too slow road construction will hinder the economic development of cities, and too fast road construction will lead to waste of resources and financial burden. Urban public transportation is one of the criteria for judging whether it is too fast or too slow. Compared with Jiaxing, Zhoushan is obviously different, and its contribution rate of urban public transport indicators is much higher than that of road network construction (reaching 0.08: 0.92 in 2020).

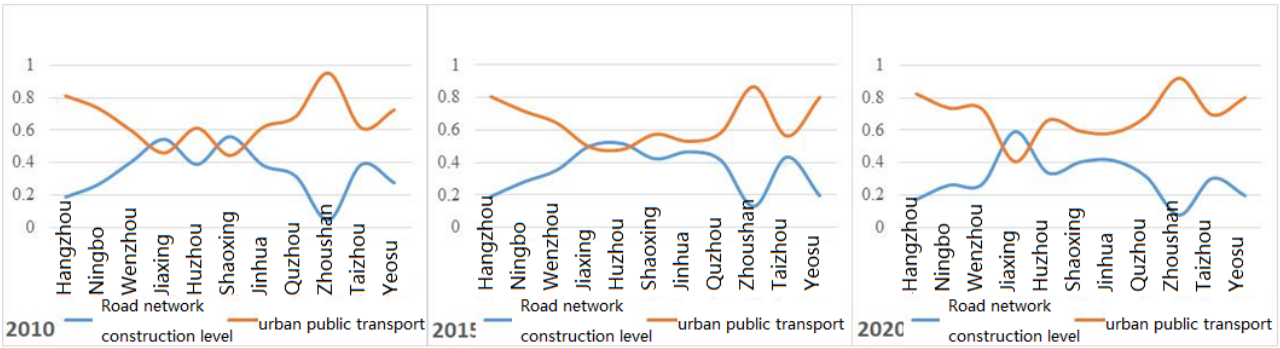


Figure 4. Contribution Rate of First-Level Indicators of Urban Transportation Construction in Prefecture-Level Cities of Zhejiang Province from 2010 to 2020

4.3 4.3 Coupling Coordination Analysis

Generally speaking, the balanced development of new urbanization and urban transportation in northern prefecture-level cities in Zhejiang Province is better than that in the south as a whole, showing a similar distribution of new urbanization and urban transportation construction. Hangzhou, Zhoushan, Ningbo, and Jiaxing have better equilibrium. The former two are basically stable in coordinated equilibrium, while the latter two are stable in high equilibrium. Taizhou and Wenzhou are steady in moderate coordination, while Huzhou and Shaoxing fluctuate between moderate coordination and high coordination. However, Quzhou fluctuates between moderate coordination and low coordination. Jinhua and Lishui have poor equilibrium, the former has dropped from moderate

coordination to low coordination, while Lishui is always in a low coordination state (Figure 5). There is no prefecture-level city with antagonistic equilibrium in Zhejiang Province.



Figure 5. Spatial Pattern of Coupling Coordinated Development of New Urbanization and Urban Transportation in Zhejiang Province from 2010 to 2020

Combined with the coordination degree of prefecture-level cities, it can be further found (Table 3) that other prefecture-level cities are in a balanced development situation at a medium and high level except for Jinhua and Lishui, and new urbanization and urban transportation show a mutually promoting development trend. When the new urbanization is ahead of urban transportation construction, the improvement of urbanization quality puts forward requirements for urban transportation construction and provides sufficient sources of funds. When urban transportation construction is ahead of new urbanization, it is necessary to promote new urbanization by promoting factor flow, improving transportation efficiency, and accelerating intra-city and inter-city communication. Hangzhou's new urbanization level far exceeds that of urban traffic construction, while Zhoushan is the opposite. This development paradigm is determined by the city's functional orientation. Hangzhou, as the economic center of Zhejiang Province, has the richest educational resources and high-quality industrial structure in the province, which has been in the stage of promoting urban transportation construction in response to the needs of urbanization for a long time. Zhoushan has obvious location characteristics with 1390 islands, bordering the Pacific Ocean in the east and Hangzhou Bay in the west. This makes Zhoushan's transportation construction have great restrictions, and waterway transportation is the main source of its urban transportation construction scores. But the economic benefits brought by transportation and its derived positive effects promote new urbanization.

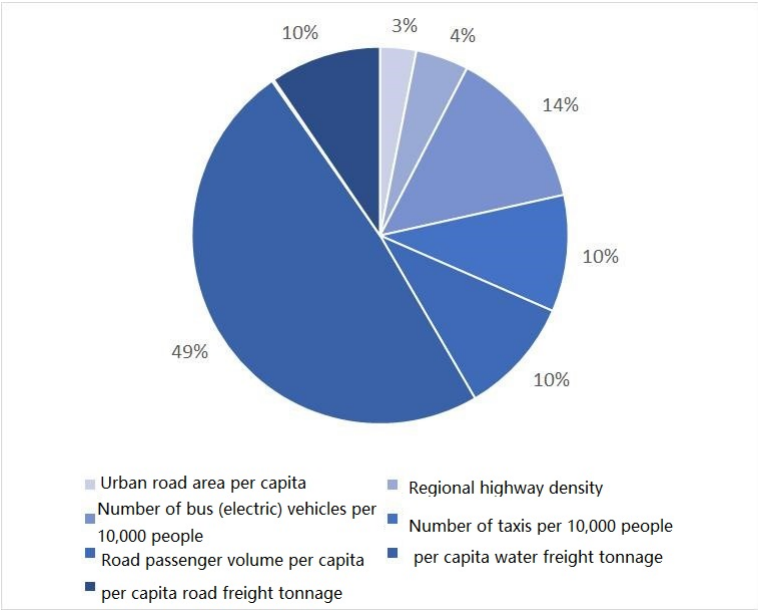


Figure 6. Contribution Rate of Main Secondary Indicators of Urban Transportation in Zhoushan in 2020

Both Jinhua and Lishui belong to the low equilibrium stage where new urbanization lags behind urban transportation construction, with a certain antagonistic relationship and mutual restriction between them. The calculation results show that there is no obvious shortcoming in the secondary index of new urbanization, and both of them are at the backward level in Zhejiang Province in road network construction. Therefore, highway construction should be accelerated according to urban development orientation and local conditions, and the level of new urbanization should be improved at the same time. Taking Lishui as an example, Lishui is rich in natural resources and maintains a high index score in the ecological civilization index (0.346 in 2020, which is the highest in prefecture-level cities). However, due to its low degree of industrialization, it lacks motivation and slowly progresses in economic urbanization and transportation construction. From Lishui's coupling coordination analysis, we can see that there are some contradictions between its backward urban transportation construction and urbanization promotion, among which the indicators reflect the backward road network construction and highway transportation, etc. Promoting transportation construction is not only an urgent task to promote economic development but also a necessary measure to improve the coordinated development of its new urbanization and urban transportation.

Table 3. Coupling Coordination Degree of Prefecture-Level Cities in Zhejiang Province from 2010 to 2020

City at Prefecture Level	D Value 2010	D Value 2015	D Value 2020
Hangzhou	0.778	0.722	0.707
Ningbo	0.698	0.673	0.671
Wenzhou	0.527	0.551	0.537
Jiaxing	0.652	0.646	0.610
Huzhou	0.605	0.594	0.634
Shaoxing	0.608	0.567	0.603
Jinhua	0.545	0.496	0.473
Quzhou	0.541	0.448	0.570
Zhoushan	0.738	0.668	0.800
Taizhou	0.527	0.577	0.550
Lishui	0.460	0.377	0.439

5. Conclusion

By establishing a comprehensive evaluation index system for new urbanization and urban transportation construction with the use of the entropy method, coupling coordination model, Jenks, etc., this paper analyzes three research scenarios of new urbanization, urban transportation construction, and their coupling coordination in 11 prefecture-level cities in Zhejiang Province in 2010, 2015, and 2020. We can see that the overall distribution is high in the north and low in the south. Apart from that, the development and construction status, as well as driving factors of prefecture-level cities are analyzed. Most of the urbanization and urban transportation in prefecture-level cities in Zhejiang Province is in the coupling stage of mutual promotion, but there are great differences in coupling quality. Most prefecture-level cities are in the coupling stage of medium and high quality, and the coupling level between Jinhua and Lishui needs to be improved. The location characteristics and city positioning of prefecture-level cities exert significant influence on the coupling state and quality.

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