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Original Research

Multi-Mode Coordinated Planning of Urban and Rural Transportation under Heterogeneous Spatial Interaction

Hong Xu*, Jin Zhao, Jialun Zheng, Tianyue Li, Meixi Chen, Haozun Sun**

School of Urban Construction, Wuhan University of Science and Technology, Wuhan 430065, China

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Abstract

Driven by the rapid construction of China's transportation and the integration of urban and rural development, a large network of different transportation modes, such as roads, railways, waterways, and aviation, have formed in urban and rural areas. The multi-mode coordinated planning of transportation has therefore become a new trend in the integration of urban and rural transportation, promoting the common development of urban and rural areas. Based on this, this paper uses multi-source data information to explore the coordinated development and planning of different modes of urban and rural transportation and takes GIS software as a tool to coordinate the development between urban and rural transportation planning and production, life, ecology and cultural elements in urban and rural space for the purpose of evaluating the traffic needs of different modes in urban and rural space. Wuxue City is taken as an example to analyze the shortcomings of the current urban and rural transportation coordination, and accordingly proposes a four-pronged coordinated traffic planning strategy: road network structure, hub layout, information service, and public transport optimization. Spatially, this paper intends to find out a new approach of coordinated planning of urban and rural multi-mode transportation which can promote the integrated development of urban and rural transportation and set a good example for the development of urban and rural transportation in other similar areas.

Keywords: urban and rural transportation, multi-mode transportation, multi-source data, heterogeneous spatial interaction, coordinated planning

Introduction

Under the strategic goal of "building China into a country with strong transportation network" clearly put forward by the 19th National Congress of the Communist Party of China, the state has vigorously promoted the development of transportation. The rapid construction of transportation has contributed to the gradual formation of a large network intertwined by multiple modes of transportation in urban and rural spaces. Under the new development situation, we must attach importance to the planning of urban and rural transportation to promote the coordinated economic development between urban and rural areas [1], narrow

*e-mail: xuhong@wust.edu.cn
**e-mail: 1176072240@qq.com

the urban-rural gap, and ultimately help the national urban-rural integration development policy.

The accelerated urbanization, promoted by China's reform and opening up, has also led to the development of surrounding areas of big cities as well as increased traffic between urban and rural areas. Consequently, transportation planning began to pay attention to the urban-rural integration mode ideologically and theoretically [2]. Problems keep emerging in the process of exploration, such as the discontinuous traffic connection in the transition zone from urban to rural area. Besides we should do more to properly handle the relationship between urban and rural transportation and overall urban planning [3] rather than just stay in the imagination. The Beijing-Tianjin-Northern Hebei region has begun to practice the exploration of combining the urban development axis with the main transportation channels, focusing on strengthening the hub and improving the comprehensive transportation system [4, 5]. While on the other hand, the demand for short-distance travel of urban and rural residents has increased as a result of the economic development, and researchers have therefore turned to explore the integrated urban and rural public transport service system [6]. In the face of the problem that the development of public transport is resticted by the small scale of small and medium-sized cities, it is necessary to optimize the bus route network at different levels in all areas within the city to develop urban public transport [7] instead of just focusing on the traditional urban areas, establish a comprehensive evaluation index system for the integration of urban and rural passenger transport with the concept of sustainable development [8], and comprehensively build an overall framework for the integration of urban and rural public transport [9]. Since the low degree of urban and rural transportation informatization and less cooperation between departments have resulted in a waste of transportation resources [10], an urban and rural public transport information database should therefore be established to coordinate multi-departmental decision-making participation [11], and on the other hand, the advent of the era of big data also facilitates data collection and analysis for urban and rural transportation planning [12]. The raised living standards and the gradually improved different modes of transportation between urban and rural areas have jointly contributed to the situation of coordinated operation of mixed travel transportation networks such as automobiles, subways, buses and water transport [13], as well as the diversified travel needs of urban and rural residents. Many scholars pay more attention to the development of urban transportation, including analyzing the characteristics of various traffic modes, building residents' travel path planning model in combination with personalized travel [14], analyzing, discussing and verifying the coupling and coordination between multiple traffic modes, pointing out the shortcomings in the coordinated development of different transportation subsystems, and finally putting forward targeted suggestions [15], yet rural transportation still lags behind in development. Considering the increasingly uncoordinated and unbalanced urban and rural transportation development, it is necessary to straighten out the urban and rural road management system and functional hierarchy, improve rural transportation information, and finally promote the completion of intelligent urban and rural transportation services [16]. Urban and rural traffic information exchange needs to be perfected so as to better coordinate all kinds of transportation and make the comprehensive transportation between urban and rural areas more efficient.

Urban and rural transportation planning mostly focused on the integration of urban and rural public transport and the system optimization of urban and rural transportation, while with the continuous improvement of different traffic modes in urban and rural space, there is relatively less research on the coordinated planning of urban and rural multi-mode transportation. Facing the implementation of the current land and space planning system, the concept and process of transportation planning have changed accordingly. In order to realize the interaction and coordination between urban and rural road network planning and other spatial elements [17], it is necessary to further explore the coordinated planning of urban and rural transportation in future research for the purpose of obtaining coordinated planning with various information elements. Therefore, this paper, based on multi-source data information and using GIS software, attempts to coordinate the development of urban and rural transportation planning with the production, life, ecology and cultural elements in urban and rural space, evaluate the spatial needs of different modes of urban and rural transportation. Besides, this paper also realizes the coordinated planning of urban and rural multi-mode transportation from the four aspects of road network structure, hub layout, information service, and public transport optimization, explores the path of urban-rural multi-mode coordinated traffic planning in space, promotes the integrated development of urban -rural transportation, and thus providing reference for the development of urban and rural transportation in other similar areas.

State-of-Art

Heterogeneous space is formed by the multilingualism, multi-temporal and spatial characteristics, multi-scale expression and diversity collection of geographic information in the absence of standard basic data in geographic information system GIS under the development of the information age, that is, the geographic information space formed by multi-source heterogeneous spatial data [18]. Considering the effective storage and management of spatial basic geographic information data is becoming increasingly important, Zhang et al. [19] realized the sharing and mutual access of existing spatial basic geographic information based on spatial data management of 0racle spatial in the face of the irreconcilable problem of data semantic expression resulted from the integration of spatial data and attribute data in most GIS software. Zhu et al. [20] solved the syntax and semantic heterogeneity of spatial information based on XML and RDF technology to achieve the consensus sharing of heterogeneous spatial information. Xu et al. [21] used heterogeneous spatial databases to design the geographic information public service mechanism for heterogeneous spatial databases which has multi levels vertically and multi databases horizontally, with a view to realizing the integration, sharing, collaborative service and dynamic update of National Geospatial Information. As urban planning tends to be refined management design, the planning and design work requires a large number of basic geographic information data and data sharing and exchange between various departments. For all kinds of design units, it is difficult to share information due to different data formats, standards and management. Therefore, major cities begin to actively explore the construction of a diversified and heterogeneous spatial information platform for the integration and sharing of geographic information resources [22, 23]. The development of heterogeneous spatial interaction technology promotes various departments such as surveying and mapping, surveying, urban and rural planning, and transportation planning to realize the sharing and interaction of various geographic information, thus reducing the waste of information resources and improving work efficiency at the same time.

There are relatively mature studies on synergy theory. The synergetic theory was first proposed and established by the German physics professor Erman Haken [24], which refers to the internal synergy of the system. To be specific, each subsystem achieves a certain connection and unity, and develops and evolves in a coordinated and orderly direction under the external action system, forming a certain stable, distinctive and orderly structure [24, 25]. The research in recent years on the application of synergy theory to the field of transportation planning mainly focuses on analyzing the interaction between the urban transportation hub and the adjacent land. For example, Cui et al. [26] sorted out the synergistic elements and processes of land use between the railway passenger stations and the adjacent areas, determined the synergistic order parameters between the two, and proposed suggestions on land use planning of adjacent areas of transportation hubs. While Cui et al. [27] put forward three planning strategies from macro and micro levels: the coordination between transportation hub stations and urban space, the multi-level coordinated development of different regions around hub stations, and the multi-dimensional spatial coordination of station form and function to realize the coordination between urban stations. The research on the coordinated development technology of the structure, scale and management of traffic space has gradually become a research hotspot among domestic scholars [28].

It can be seen from the above-mentioned studies on coordinated transportation planning that more attention be paid to urban transportation hub stations, while there is less research on coordinated planning of urban-rural multi-mode transportation. This paper therefore discusses the methods and ideas of urban-rural multi-mode coordinated transportation planning based on heterogeneous spatial interaction. Using ArcGIS software to normalize all kinds of basic geographic data, this paper, combined with analytic hierarchy process to quantify decision-making [29], achieves the interaction of production, life, ecology, culture and other diversified heterogeneous spatial geographic information data in urban and rural traffic space, guides traffic planning and coordinates various elements of urban and rural space. Besides, we explore urban and rural coordinated transportation planning strategies in terms of road network structure, hub layout, and information services, fully realize the coordinated development of different modes of transportation in urban and rural space, thus providing new methods and paths for urban and rural transportation development.

Material and Methods

Study Area

Wuxue City in Hubei Province is the study area of this study. Located on the north bank of the middle reaches of the Yangtze River, it is adjacent to the Dabie Mountain in the north and the Yangtze River in the south. At the intersection of the "Beijing-Kowloon" Railway, "Shanghai-Chengdu" Expressway, the Yangtze River, a large transportation pattern of railway, road and waterway supporting intermodal transportation has

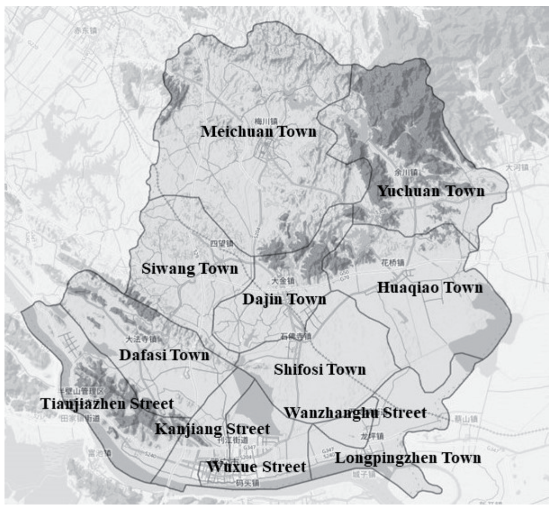

Fig. 1. Administrative map of Wuxue City.

been preliminarily in place. The research scope selected in this paper is the whole area of Wuxue City (Fig. 1), with a total area of about 1200.35 square kilometers, and the administrative divisions of streets and towns in Wuxue City are used as the analysis base map, including four streets and eight towns. In view that an important part of the Wuhan City Circle and an important port city in the middle reaches of the Yangtze River, and a variety of traffic converges here, we selected this area as the research object, to better promote the development of Wuhan city circle.

Research Framework

In general, this paper studies the urban-rural multi-mode traffic planning from the spatial level, Through the study of relevant literature, the key points of urban-rural multimodal transportation collaboration are extracted from the four aspects of infrastructure, hub connection, information service and road grade, as the research theory guide of this paper. On the basis of existing research, the main influencing factors are determined by selecting urban and rural spatial multimodal traffic routes, the weights of various influencing elements are determined based on the statistical averaging method, the heterogeneous spatial database is constructed through ArcGIS, the spatial traffic space demand of urban and rural multi-mode traffic is analyzed, the spatial traffic connection characteristics are analyzed based on mobile phone signaling data and industrial connection information, the passenger and goods flow traffic corridor are identified, and the problems and needs of multimodal traffic coordination in the region are summarized and studied in combination with the previous theoretical research. Under the guidance of problems and needs, the article finally proposes the urban and rural multimodal transportation planning strategy in hope of promoting the spatial construction of the urban-rural transportation network characterized by orderly connection, efficient operation and green and harmony. The research framework is shown in the figure below (Fig. 2).

Theoretical Guidance on Urban-Rural Multimodal Transportation Collaboration

The urban agglomeration located in the middle reaches of the Yangtze River has basically formed expressways, railways and water transport channels, as well as a multi-mode transportation system dominated by roads and supplemented by railways, waterways and aviation [30]. The general transportation system in urban and rural areas of small and medium-sized cities, however, does not involve aviation. Therefore, this paper selects road, railway and waterway for coordination research among the three modes of transportation.

Among all kinds of modes of transportation, the road serves as the most basic internal transportation system of the city, connecting all kinds of resources in the city, assisting other transportation, shortening

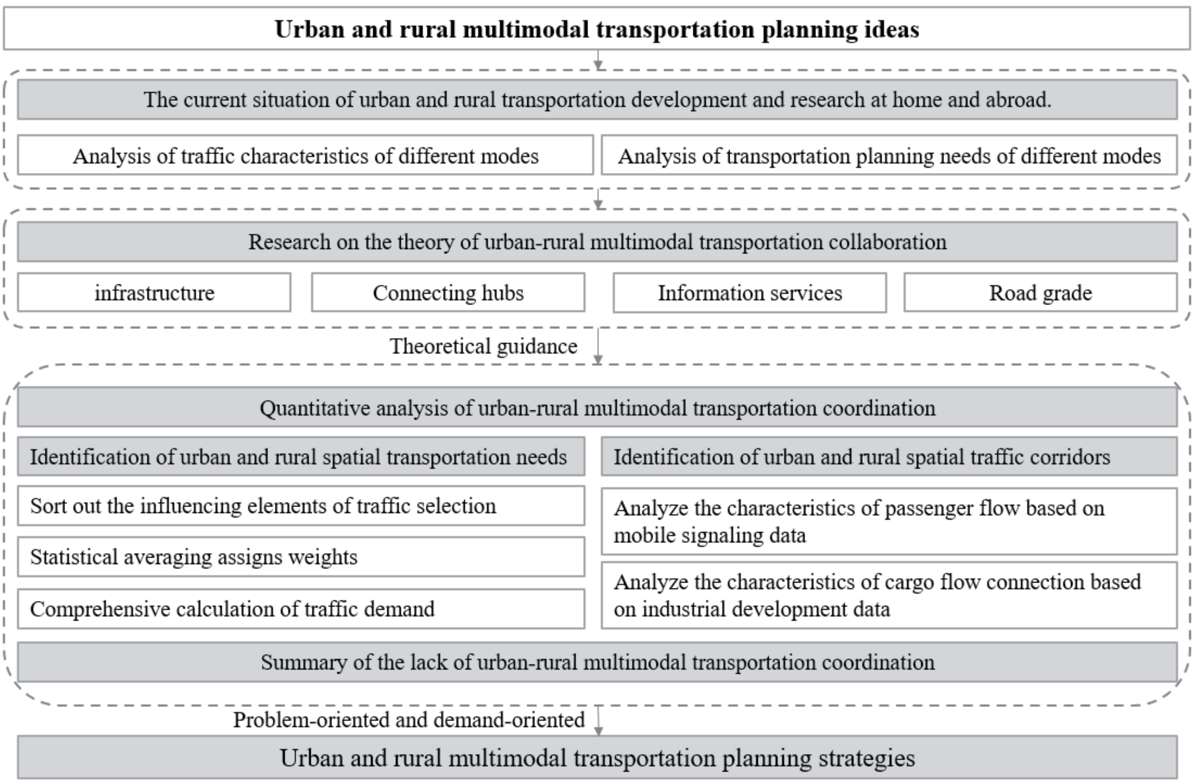

Fig. 2. Research framework.

the distance of industrial parks within the city and between different cities, facilitating the transportation and sales of commodities and meeting the travel needs of the people. The railway mainly undertakes the transportation between urban agglomerations, which can supply unique materials between cities and promote the cargo operation of regional secondary industry while waterway is mainly concentrated in the Yangtze River and the southeast coastal area, whose development is limited by the number of ports, natural conditions, etc. though it can carry out a large number of long-distance transportation [31]. According to the above introduction of different transportation functions and characteristics, the road-railway coordination, road-waterway coordination and waterway-road railway coordination can be promoted from four aspects: infrastructure, hub, information service and road grade, so as to make full use of resources and improve transportation efficiency.

(1) Infrastructure

It is necessary to re-evaluate the existing road, railway and waterway planning from the needs of social and economic development in order to reduce duplicate and blind construction [32], sort out the companies and industrial parks that need to transport bulk goods such as coal and minerals and rationally build special railway lines to improve the efficiency of cargo transportation [33]. At the same time, material distribution centers can be built near railway passenger stations to connect with urban roads to meet urban material transportation needs. On the other hand, through integrating coastal ports, unifying construction standards and reasonably matching the transportation channels and nodes of roads and waterways to connect with the road network, the port collection and transportation capacity can be improved.

(2) Hub

The construction of different transportation connection hubs should adapt to traffic lines and regional transportation needs, reasonably arrange the comprehensive transportation hubs such as high-speed entrances and exits, passenger stations and ports in combination with the urban industrial cargo transportation concentration area, crowd travel concentration area and urban development structure. The management standards of all departments need to be unified, and the transportation hubs at different levels should have corresponding division of labor management, so as to improve the overall capacity of the hub.

(3) Information Service

For road, railway and waterway transportation information, including transportation channel direction, passenger and freight traffic, traffic accidents, hub information, transportation enterprises, weather impact and other information, modern network technology should be applied to establish a multi-mode traffic information integration system to realize information sharing and real-time update among different traffic forms. Through information reorganization, we can innovate multi-mode traffic coordination pattern and improve the dynamic monitoring management and efficient service ability between different traffic forms.

(4) Road Grade

Since the internal traffic between urban and rural areas is dominated by roads, a hierarchical road network system at all levels should be established in combination with the urban and rural system structure, and the corresponding division of labor and cooperation should be carried out for different levels of roads, so as to promote the coordination of roads at all levels and the overall development of urban and rural public transport. The urban and rural architecture should be based on the scale level of the central urban area, the central (key) town, the general town, and the rural community. Hence, the first-level urban and rural road network connects the urban area with the central town and the general town, the second-level connects the town and various rural communities, the third- and fourth-level reasonably connects the rural settlements. In this way, by improving urban and rural road networks at all levels, the primary and secondary planning of public transport can be clarified. Relying on the first and second road networks to plan the main lines of public transportation services, serve the transportation links between cities and towns, arrange large passenger vehicles, and increase the frequency of bus operations. The three- and four-level road network plans secondary public transport service lines, improves the coverage of public transport services, arranges small vehicles, and arranges operating shifts according to the actual traffic travel volume, to finally improve vehicle service efficiency and enhance the economic benefits of enterprises.

Methods of Identifying Spatial Traffic Needs

To determine the location of urban and rural multi-mode traffic routes, it is necessary to fully consider the main influencing factors of traffic route selection in urban and rural spaces, so as to rationally plan the comprehensive transportation network.

Basic Principles of Traffic Route Selection

Traffic routing is a complex system engineering. Different modes of traffic planning should be combined with local terrain, features and ecological environment, and consider the cost of project construction, the impact on social and economic development, and the transportation needs of urban and rural residents, to achieve the optimal traffic planning scheme. Through the analysis of existing data and scientific research [29, 33], the selection of traffic route selection indicators in this paper follows the following principles: (1) Combined with local traffic planning, environmental protection planning, etc., as well as the nature and service positioning of various types of transportation. (2) Meet the basic traffic capacity and safety elements.

(3) Consider the impact of the natural ecological environment such as terrain, geology, hydrology and climate of the place of transportation, and try to avoid ecologically sensitive areas to reduce ecological intrusion and destruction. (4) Consider the type of land through which traffic passes, and do not occupy or occupy less cultivated land and residential land. (5) Give priority to the selection of route schemes with low engineering volume, low energy consumption, high economic benefits and good performance of technical indicators, so as to achieve energy conservation and carbon reduction, and ultimately achieve the vision of carbon neutrality.

Traffic Route Selection Influence Factors

Transportation plays a role as a transmission hub for urban life, production, entertainment, etc. Since in urban and rural living space, the place of residence, supporting service facilities and work places are the main concentration of citizen activities, and the traffic between the three is frequent, and its distribution affects the direction of traffic lines and the layout of traffic stations to a certain extent. three types of influencing factors of urban and rural settlements, public service facilities and workplace distribution points are selected. In urban and rural production space, important urban enterprises and industrial zones need good external transportation production product transportation channels, and the transportation routes are close to the industrial zone to facilitate the transportation of goods, reduce transportation costs and losses in the process of product transportation, and promote urban economic development. The influencing factors such as the distribution points of important economic industrial areas selected. In urban and rural ecological space, topography affects the construction conditions of traffic projects, flat areas can reduce the amount of filling and digging, improve the economic benefits of the project, ensure traffic safety, and at the same time, based on the principle of ecological priority, reduce the damage to the ecology of landscapes, forests, lakes and grasses [17], and protect the ecology to the greatest extent. Two kinds of influencing factors, landform and ecological protection area, are accordingly selected. And in urban and rural cultural space, transportation links can play the role of driving cultural exchanges between cities [29], so reasonable lines should fully protect and utilize historical and cultural resources and important scenic tourism resources. Two types of influencing elements are therefore selected: historical culture and distribution points of scenic tourism resources. A total of eight influencing factors are selected for study (Table 1) based on based on the above principles and impact analysis.

Determination of Metric Weights

In the weighting of influencing factors of transportation planning, the principle of basic accessibility and ease of operation adopts the expert survey method, which gives full play to the subjective initiative of individuals, but the subjective influence of indicator empowerment is also the limitation of this method. This article simplifies the steps of this method to facilitate operational calculations. The established index evaluation system and indicator descriptions, the overview of the research area, the weight questionnaire and other information will be sent to *m* experts in relevant fields, and opinions on the importance of indicators will be solicited, and various indicators will be scored on a 10-point system. Statistical analysis of the score of the recovered questionnaire, first of all, the assigned score of each expert is normalized, and the preliminary weight of the kth expert on various indicators i is calculated W_i^k (k = 1, 2, 3..., m) can be obtained by formula (1):

Table 1. Statistics of the influencing factors of transportation planning.

	Space type	Influencing features	Specific content
Influencing factors of transportation planning	Urban and rural living space	Place of residence	Settlements in urban and rural areas,
		Public service facilities	Education, sports, medical and other living service facilities
		Workplace	Concentration of business offices
	Urban and rural production space	Important industrial production area	Agricultural product processing site, grain production base, building materials processing base, shipbuilding base, etc
	Urban and rural ecological space	Topography	Elevation, slope
		Ecological reserves	Important water systems, woodlands, biological habitats, etc
	Urban and rural cultural space	History and culture	Ruins, historical and cultural reserves, etc
		Scenic tourism resources	Geographical landscapes, landscape architecture, scenic areas, etc

$$W_i^k=\frac{a_i}{a_1+a_2+\cdots+a_i}(k=1,2,3,\ \ldots,\ m) \quad (1)$$

$$W_i=\frac{W_i^1+W_i^2+\cdots+W_i^k}{k}\ (i=1,2,3,\ \ldots,\ n) \quad (2)$$

Then equation (2) calculates the average of the preliminary weights of the n-class indicators to determine the weights of various influencing factors, the statistical table of the weights of influencing factors of final transportation planning can be obtained (Table 2).

Data Acquisition

After looking up the access ways and methods of modern big data [34], the data acquisition approaches of the main influencing factors of transportation planning involved in this study are summarized in the following table (Table 3).

Computational Analysis

This study processed, quantified and normalized the experiment data within ArcGIS. Firstly, for urban and rural living space, residence, public services, and work areas are the destinations for people's daily travel, and the more places there are, the more people travel and the higher the traffic demand. Second, for urban and rural production space, important enterprises, industrial parks, etc. need to transport production commodities internally and externally, thus the more concentrated enterprises and production bases are, the more freight and traffic demand is. Third, for urban and rural ecological space, it is more suitable for traffic construction in areas with flat terrain, where the traffic demand is accordingly higher. And constructive damage should be reduced in important ecological protection areas with low traffic demand. For urban and rural cultural spaces, it is suitable, on the premise of protecting history and culture, to show the regional cultural characteristics near the traffic line and the area where scenic tourism resources are located needs to build transportation to promote the development

Table 2. Statistical table of weights of influencing factors of transportation planning.

	Space type	Influencing features	Weight
Influencing factors of transportation planning	Urban and rural living space	Place of residence	0.112
		Public service facilities	0.104
		Workplace	0.087
	Urban and rural production space	Important industrial production area	0.183
	Urban and rural ecological space	Topography	0.124
		Ecological reserves	0.184
	Urban and rural cultural spaces	History and culture	0.102
		Scenic tourism resources	0.104

Table 3. Access to research data.

Influencing features	Data form	Data sources
Place of residence	Distribution points of urban and rural settlements	The nature of the land use, remote sensing image data
Public service facilities	Distribution points of various types of public service facilities	POI data
Workplace	Centralized distribution points of business offices	POI data
Important industrial production area	Distribution points of important enterprises and production bases	Socio-economic reports, statistical yearbooks
Topography	DME	Geospatial data cloud
Ecological reserves	Distribution area of the current situation of the natural environment	Remote sensing image data
History and culture	Distribution points of historical and cultural resources	Google Maps data
Scenic tourism resources	Scenic tourism resource distribution point	Google Maps data

of tourism. The more concentrated the two, the higher the traffic demand. Based on this, the density analysis of the factors is carried out sequentially by ArcGIS software, and the output results are divided into five levels, each of which is given a score of 1-5 from low to high, and the ecological protection elements values are negative. Then raster algebra superposition calculation is carried out according to the weight of various influencing factors to comprehensively obtain the spatial demand analysis map of urban-rural space multi-mode traffic. Each raster value from high to low indicates that the traffic demand decreases gradually.

Methods of Traffic Corridor Identification

In view of the obvious functional bias of land use of villages and towns in urban and rural space, the clear industrial layout and the concentrated space, and the obvious temporal and spatial characteristics of people's travel, the characteristics of traffic flow between villages and towns are therefore obtained based on mobile signaling data, and OD analysis is achieved through data processing, so as to count the traffic volume within villages and towns and that to other villages and towns. Through the quantitative analysis of the spatial activities of people, the connection characteristics of urban and rural spatial traffic passenger flow are extracted to define the spatial traffic corridors with large passenger traffic volume as the basis for the planning of traffic facilities with road as the skeleton. In the near future, the grades of road connecting traffic arteries can be upgraded between townships and towns with close traffic, and in the long run, joint operation of public transportation between townships and towns can be developed, which will promote the networking of public transportation lines, as well as expand urban and rural accessibility and the overall development of urban and rural areas.

The industry of urban and rural space relies on transportation construction, and the industrial space that has begun to take shape will bring new traffic needs. The two kinds of interactions to promote economic development. Sort out the current situation of industrial distribution through the network platform, draw an industrial distribution concentration belt along the industrial agglomeration area, sort out the urban industrial planning information to obtain the urban industrial planning development axis, collect regional economic contact information, government statistical yearbook and industrial development report, etc. to determine the direction of the city's external industry docking. Taking the overlapping part of the concentrated belt of urban industry status, the direction of regional industrial docking and the axis of urban industrial planning and development as the main industrial spatial connection, relying on the existing external traffic to draw a virtual network of freight transportation corridors, that is, the main spatial channels for the transportation of industrial production products, so as to analyze the characteristics of goods flow, judge whether the existing traffic and freight are convenient, whether a rapid transportation system or a large number of transportation systems are needed, and choose the appropriate transportation mode. It is also possible to choose a variety of transportation modes for reasonable coordinated planning to form a convenient cargo flow transportation system between industrial supply and demand (Fig. 3).

Results and Discussion

Data Processing and Basic Analysis

The basic data are determined from the production, living, ecological and cultural factors on which urban and rural transportation development depends. This paper collects the POI data, remote sensing image data, mobile phone signaling data and other data of various

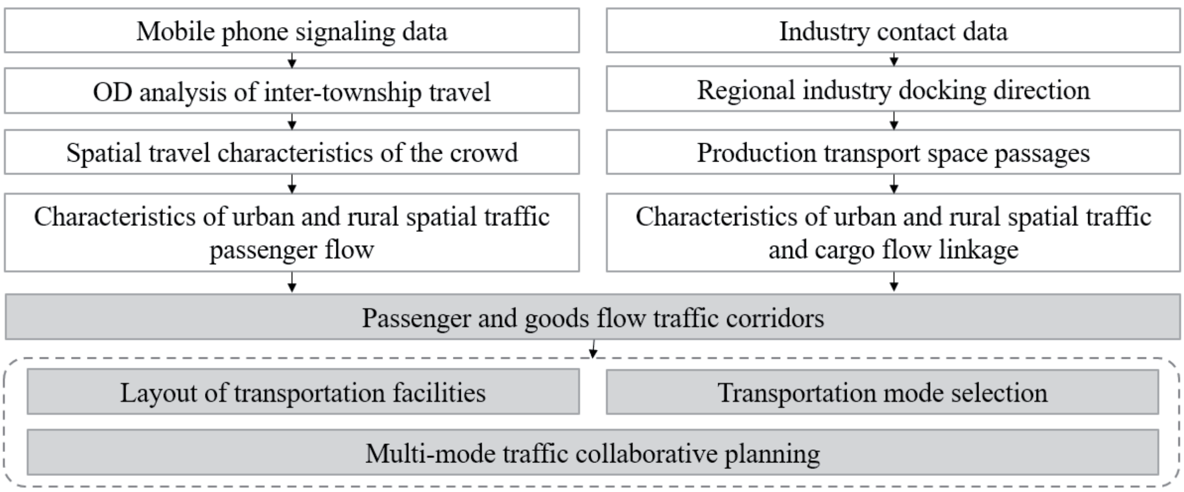

Fig. 3. Analysis of urban-rural spatial transportation links.

Table 4. Types and sources of research data.

Influencing features	Information obtained	Data sources
DME data	Elevation, slope, aspect	Geospatial data cloud website
Points of interest	All kinds of public service facilities, commercial facilities, transportation service facilities, etc	Google Open Platform
Mobile phone signaling data	OD analysis of passenger flow	Enterprise
Traffic vector data	Traffic status	The website of Open Access Library, Hubei Transportation Statistical Yearbook
Remote sensing imagery map	Rural settlements, urban construction areas	The website of Google Earth Engine
Enterprise data	eEnterprise geographic information data	Baidu Map, Statistical Yearbook

service facilities in Wuxue City (Table 4). Then all types of data are endowed with geographic information, geographical coordinates are unified and the database of various information are built through the ArcGIS platform.

Under the regional and urban traffic development trend of Wuhan city circle development and Huanggang economic and social development, Wuxue will continue to improve the construction of water transport, roads, railways during the "14th Five-Year Plan" period to improve the traffic accessibility between Wuxue City and the surrounding areas and reasonably develop urban and rural transportation. In the long run, this will have a positive impact on urban and rural spatial development direction, spatial layout, land organization and other aspects of Wuxue City, and what's more, to promote the overall development of urban and rural areas.

Wuxue City has now built a total length of 2483.5 kilometers of roads, the density of the road network reaching 199.3 km/square kilometer, and the road through the village has accounted for 42.48%. The Wuxue section of the Mayang Expressway has been gradually completed. All townships have achieved 30-minute interconnection, yet there is insufficient connection between different grades of roads. In the basic analysis of urban and rural living space (Fig. 4a-c), the living space of Wuxue City is concentrated in the north, south and central areas, showing the characteristics of non-linear and multi center clusters. The recent planning of Wuxue should focus on the balanced development of the several modes of transportation while the long-term one should be dominated by public transportation [35]. The transportation needs to be improved in the north and central areas, and new construction, route change, upgrading and road section expansion need to be carried out in some areas. In the basic analysis of urban and rural ecological space (Fig. 4d-f), the important ecological reserves, also the cultural elements that need centralized protection and utilization (Fig. 4h, i), of Wuxue City, facing the Yangtze River with mountains behind it, are concentrated in the northeast and southwest. The rational construction of ring roads in these areas can reduce the damage to the ecology, and promote the development of eco-tourism and the publicity of urban and rural cultural features.

Wuxue Port and Wuxue Yangtze River Road Bridge in the south of Wuxue City are now under accelerated construction. In the basic analysis of urban and rural industrial space (Fig. 4f), important industrial bases are concentrated in the west and south, while Wuxue City lacks special industrial wharf and special railway line. At present, a comprehensive industrial wharf has been built, and the comprehensive Tianzhen building materials wharf and special chemical wharf are being constructed relying on Wuxue port. Under the goal of integrating into the large transportation network of Wuhan city circle, Wuxue should make full use of intercity railways and water transport along the Yangtze River, comprehensively consider the combined transportation of water transportation, road and railway especially in areas where commodity production enterprises are concentrated. In this way, it can improve the efficiency of industrial goods transportation connected with the surrounding urban agglomeration and promote the economic development, so as to drive the comprehensive development of multi-mode transportation in urban and rural areas.

Transportation Demand Analysis

The processed data are weighted by raster algebra calculation to comprehensively identify the urban and rural spatial traffic demand identification. Judging from the research results (Fig. 5), the traffic demand of Wuxue City, concentrated in township areas along the Yangtze River in the south and of the central axis, shows the spatial characteristics of circular and nonlinear distribution. Thus it is necessary for Wuxue City to establish a multi-level transportation system to strengthen the traffic connection of each section. Most of the traffic demand with a score of more than 2.7 are distributed along the existing traffic pattern, but the road network construction in each section is quite different, which makes the connection between the north and the south quite inconvenient. In addition, the density of

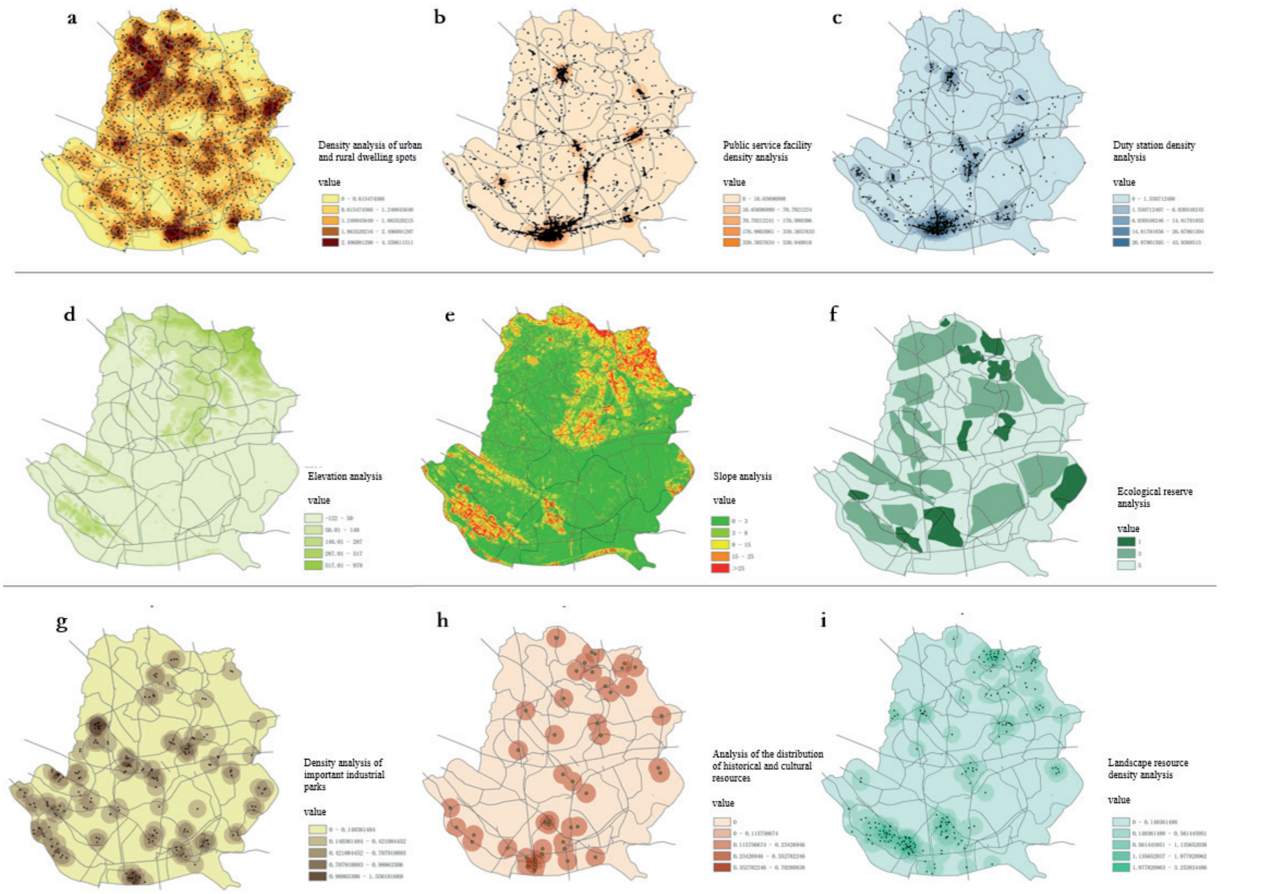

Fig. 4. Density analysis of residence a), public service facilities b) and workplace c). Analysis of elevation d), slope e), and ecological reserve f). Density analysis of important industrial sites g), historical and cultural resources h) scenic tourism resources i).

transportation facilities in the mountain concentrated area of Wuxue City is significantly lower than that of villages and towns in the southern plain, and the scattered distribution of ecological and cultivated land concentrated areas also helps define the development mode of urban and rural public transportation in the city dominated by multi-layer road network.

Traffic Connection Analysis

Analysis of Passenger Flow

The regional OD analysis of urban and rural spatial traffic passenger flow can be carried out through ArcGIS software based on mobile phone signaling data. From the OD analysis of passenger flow in Wuxue City (Fig. 6), the net inflow and outflow of Wuxue Street are relatively higher, followed by Meichuan Town, Huaqiao Town and Shifosi Town. Wuxue Street has strong connections with Shifosi Town, Huaqiao Town, Meichuan Town, Longping Town and Tianzhen Street, presenting the north-south traffic passenger flow connection axis of Meichuan-Dajin-Shifo Temple-Wuxue and the east-west traffic passenger flow connection axis of Tianzhen-Wuxue-Longping along the Yangtze River at the southern end of Wuxue City. The overall traffic connection intensity shows a spatial development pattern with Wuxue Street as the intersection and "one horizontal and one vertical". It is therefore feasible to increase urban-rural intermodal bus and reasonably design intermodal bus routes. Since the townships are mainly connected between Meichuan Town, Yuchuan Town, Huaqiao Town, Shifosi Town,

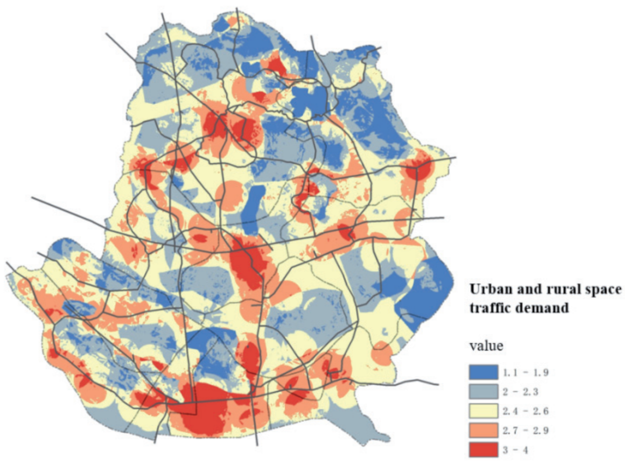

Fig. 5. Identification of urban and rural spatial transportation needs.

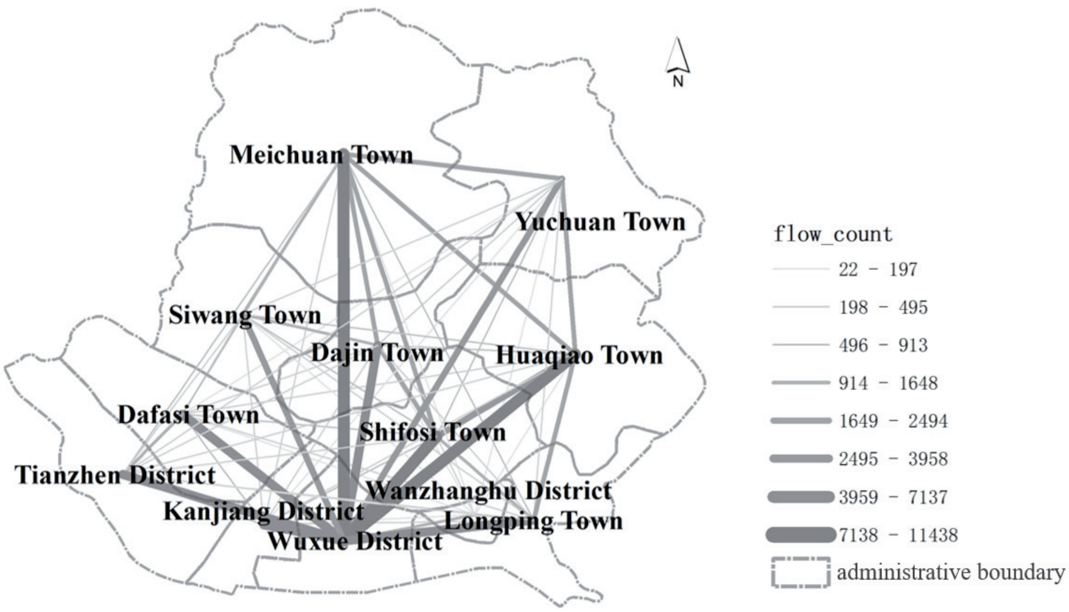

Fig. 6. OD analysis of passenger flow.

and Dajin Town, circular transportation facilities can be set up to evacuate urban traffic gathering for the passenger flow connection is circular.

Analysis of Goods Flow

Sorting out the current situation of the industrial layout of Wuxue City, "Huanggang Statistical Yearbook 2020", "Hubei Transportation Yearbook 2020", Wuxue City Industrial Layout Planning and related industrial media news reports, etc., it is found that the industrial links of Wuxue City are mainly concentrated in the northern eco-tourism and agricultural area, the central industrial zone and the industrial zone along the river, relying on provincial highway 308, Hu Rong expressway, 228 county road and national highway 347 to obtain the main industrial commodity transportation traffic corridor (Fig. 7). It can be seen from the analysis of cargo flow in Wuxue City that there are three main industrial freight corridors in the north, middle and south. The northern Yuchuan Town, Meichuan Town and Siwang Town develop agricultural product processing industry and ecological tourism, the central Dajin Town, Shifosi Town and Huaqiao Town develop the integrated industrial chain of raw material production – product processing – product sales,

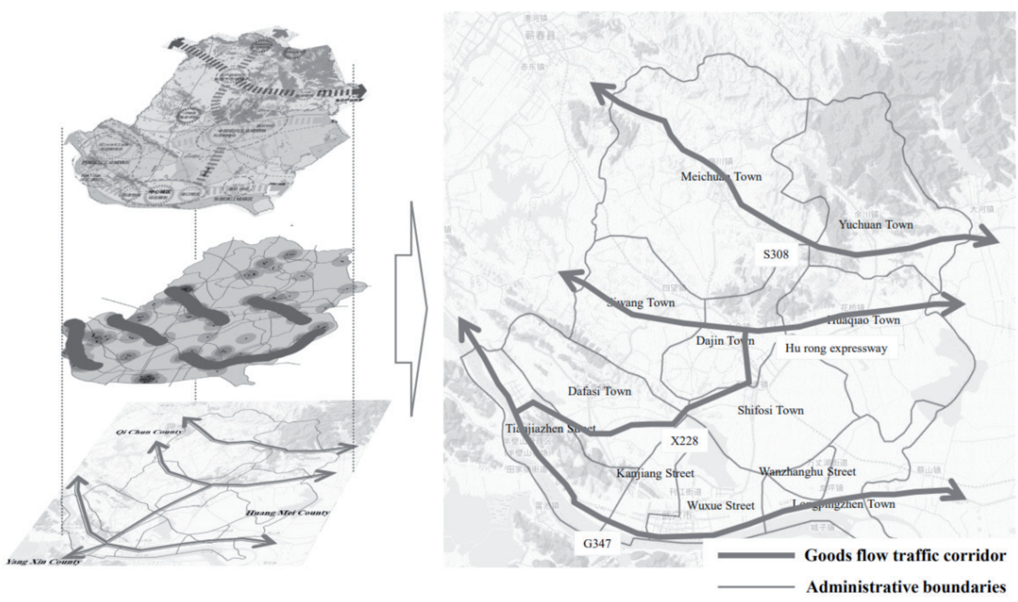

Fig. 7. Analysis of cargo flows.

the western Binjiang District Siwang Town and Dafasi Town develop the manufacturing industrial park, and the eastern Binjiang Street Township develops modern logistics and tourism services. The functional space of each township is clearly divided, showing a situation of cluster-type and multi-point balanced distribution development, which obviously relies on the existing traffic layout. Consequently, the northern ecological town area is suitable for reasonable upgrading and new roads construction to form a multi-level road network system while the central part can make use of existing railway and road for coordinated planning to strengthen vertical regional links. The south can take advantage of the port and railway transportation to expand the scale of the park. The rational construction of transportation hubs and the development of special industrial transportation lines can help achieve the overall development of urban and rural industries and form an efficient transport system with integrated transportation.

Multimodal Transportation Collaborative Planning Strategy

Coordinated Layout of Urban and Rural Transportation Comprehensive Hubs

At present, there is a lack of clear concept of comprehensive transportation hub in literature. In order to clarify the research object and focus, the transportation comprehensive hub mentioned in this article emphasizes that a variety of transportation infrastructure are connected and gathered here, and multiple transportation lines meet here to form a large node in the transportation network, including multiple transportation modes, where people and goods can transfer, be transited and then flow to other transportation lines. The rational layout of the comprehensive transportation hub is conducive to realizing urban internal transportation distribution and coordinating the cross-regional travel activities served by different transportation modes [25]. From the perspective of the characteristics of urban and rural area development and transportation demand, people travel mainly by car and railway and passenger transport lines are usually arranged on highways, national and provincial trunk roads. between urban and rural areas. Large passenger transfer hubs are generally set in areas with concentrated passenger flow such as railway passenger stations, wharves, stations [11], and the stations usually cover important townships and towns, showing the balanced layout characteristics of multi centers in urban and rural space, which is similar to the features of urban and rural traffic space demand. And the lines connecting with the hub surrounds the township center in a circular network.

Accordingly, based on the identification and analysis of traffic demand in combination with the spatial characteristics of different areas of urban and rural areas and the existing traffic construction conditions, it is divided into four levels according to the location: central urban area, suburban area, town area and central village so as to reasonably plan and lay out the comprehensive urban and rural transportation hub. Though the central urban area bears greater traffic pressure, its transportation network is relatively perfect as the interaction of a variety of traffic modes, providing many routes to choose from. The layout of intercity passenger transport should therefore be connected with bus lines in the city, but avoid traffic congestion caused by proximity to large bus hubs. The suburbs of the city play the role of dispersing the traffic volume of the central urban area. Usually the railway hubs and the waterway hubs are distributed on the edge of the city and the railway hubs are connected with passenger hubs, and ensure that the collection and distribution channels can quickly connect with expressways and provincial roads. On the other hand, the integration of port resources in the port areas along the Yangtze River and the construction of collection and distribution channels in each port area can quickly connect with roads, railways and other external transportation facilities. The comprehensive transportation hubs of towns and central villages along the Yangtze River can be arranged in the edge areas of villages and towns according to the traffic demand, and at the same time, the entrances and exits and interchanges shall be reasonably set on the high-speed line to ensure convenient traffic connections at the entrances and exits. In view of the characteristics of the urban-rural spatial structure, it is advised that urban-rural comprehensive transportation hubs adopt multi-level coordinated layout, presenting a multi-center and tree-like evacuation traffic flow (Fig. 8), thus coordinating the combined transportation of roads, railways and waterways, as well as the layout of various transportation stations and routes.

The downtown area of Wuxue is located at the southern end along the Yangtze River, the northern suburban area is close to the railway hub, and there are water transport port resources in the south. Besides, two major expressways pass through the city vertically and horizontally. Reasonably setting up interchanges and entrances and exits along expressways near important villages and towns, industrial parks and port areas can help ensure convenient traffic links at the entrances and exits, make up for the north-south traffic links, and further strengthen the traffic links between villages and towns in Wuxue City and surrounding provinces and cities. In addition, it is necessary to integrate port resources along the Yangtze River, rationally lay out the functions of the port area to connect public transportation lines, and add special railway lines in industrial parks to serve the collection and distribution of ports and the transportation needs of industrial parks, so as to enhance the convenient connection between freight and regions.

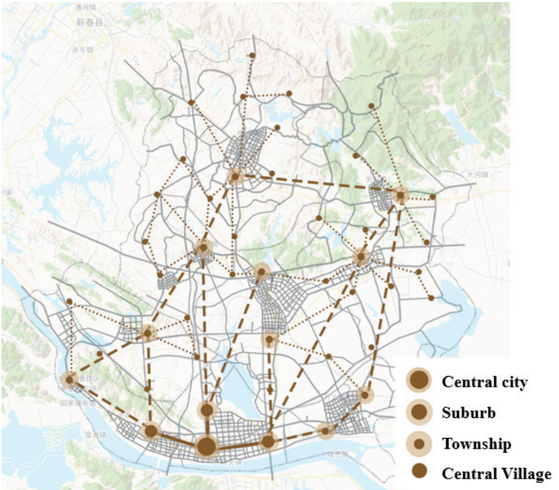

Fig. 8. Multi-level comprehensive transportation hub.

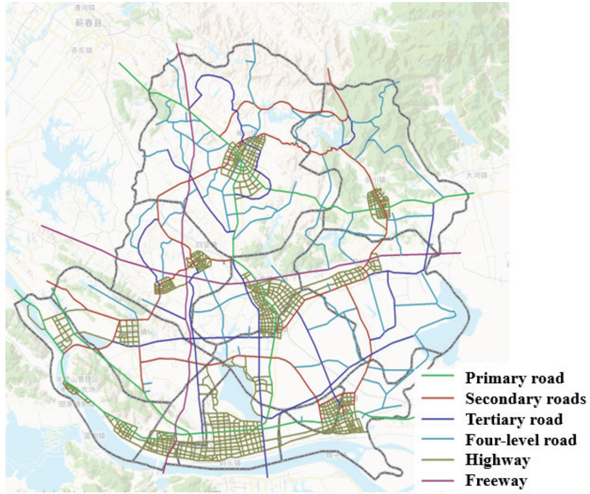

Fig. 9. Multi-level traffic network structure.

Coordinated Distribution of Urban and Rural Traffic Road Network Structure

Affected by the spatial scale of urban and rural areas and social and economic development, the current transportation network system operating in cities and counties is dominated by roads, where the construction of transportation infrastructure can be improved by adopting the multi-level road network system. Specifically, the road can be divided into four grades: class I Road, class II Road, class III road and class IV road. A hierarchical road network structure (Fig. 9) can be therefore established to realize the connection of water transportation, road, railway and other transportation modes. And specialized industrial transportation branches and tourism routes can also be built to coordinate the development of industry, tourism and other industries in urban and rural areas.

Considering the scattered distribution of villages and towns in Wuxue City, a ring-shaped class I road network can be built between villages and towns to avoid the interference of transit traffic on urban and rural development. With the class I road network covering the whole city, the class II roads connect the class I roads with rural communities so as to strengthen the connection between urban and rural areas. While class III and class IV roads constitute the rural road network, which is reasonably connected with urban and rural residential areas, thus forming the road network structure of Wuxue City. The passenger flow OD is mainly allocated to the current road and the newly constructed multi-level road network based on the shortest path selection. As can be seen from the following table (Table 5), in the area where the original traffic flow is increased, by improving the original road grade and building new roads at all grades, the traffic volume of the current road is allocated to the newly built parallel roads according to the road grade and passenger flow direction. As a result, the current road traffic passenger flow has decreased significantly, as well as the traffic congestion, thus improving the transportation efficiency of the overall road network in the city. In the port area and industrial base, roads should be built to connect with provincial highways, so as to promote the rapid connection between port dredging and industrial park dredging transportation roads and external

Table 5. Comparison before and after improvement of the traffic road network.

	Section number	Current road	Planning roads		Reduction
		Passenger flow	Planning	Passenger flow	
	1	28556	Upgraded to class I road, and newly built class III road in parallel	21417	25%
Note: The light-blue thick line indicates the current road, and the dark-blue thin line indicates the new road	2	15835	Newly built class III road in parallel	13196	16.7%
	3	5428	Newly built class II road in parallel	3877	28.6%
	4	41145	Newly built class III road in parallel	28706	30.2%

transportation. In the eco-tourism area, the tourist routes should be integrated and connected with the road network, the existing roads should be upgraded in the port area along the Yangtze River, and the class I roads along the Yangtze River should also be reconstructed for the purpose of joining the integrated development of the Yangtze River Economic Belt, and promoting the opening and development of the economy along the Yangtze River. To sum up, the comprehensive transportation road network will guide the development of ports, industrial zones and tourist areas in the city, and further realize the social and economic development of Wuxue City.

Coordinated Construction of Urban and Rural Traffic Information Services

Combining modern information technologies such as big data and cloud computing with the transportation industry, and integrating urban and rural transportation information resources will contribute to the high-quality development of urban and rural transportation [16]. Functional departments of different modes of transportation should share urban and rural traffic information data [36], in order to reduce the waste of transportation resources and improve transportation efficiency at the same time. Using the network platform to cooperate in integrating information to establish interconnected information databases will also help promote smart technologies into the countryside. Network information technology can reduce the workload of traffic information recording. After the transportation departments of different modes provide information such as transportation market demand, real-time transportation situation and transportation supply and demand in urban and rural space on the same platform, the coordination of urban and rural multi-mode transportation can be evaluated through dynamic monitoring. With the above efforts, it is feasible to promote the comprehensive analysis and continuous improvement of the problems existing in urban and rural transportation route selection, comprehensive hub layout and transportation network structure, so as to make each transportation subsystem of urban and rural comprehensive transportation develop towards a unified goal. At the same time, an information-based public transport management system can be established to guide the priority development of urban and rural public transport, add bus dedicated phases at road intersections, and set up bus sensing signals to adjust the time of signal lights as an effort to achieve public transport priority at intersections through time priority. In addition, building an urban and rural traffic information service platform, where users can query all kinds of transportation information and order tickets online, is also beneficial to improve the quality of urban and rural transportation services.

Coordinated Development of Urban and Rural Public Transportation

In the context of the urban public transport development strategy and the integrated development of urban and rural areas, priority is given to the development of public transport. Urban and rural public transport needs to adjust the current passenger transport mode with mixed lines and chaotic competition. On the other hand, urban and rural spaces take various urban areas and characteristic towns as important nodes and trunk roads as links. In order to improve the level of public transport services, we should increase the public transport service population and expand the service area, make public transport an important way for residents to travel, and realize the coordinated development of urban and rural public transport. In consideration of the general urban system structure of "central urban area – central town – characteristics town – general town – rural community" in urban and rural areas, bus lines can be set as five types of networks: central urban area – urban area, urban area – urban area, characteristic town – urban area, urban area – rural community, characteristic town – rural community, with focus on the primary and secondary division of bus lines (Fig. 10). The important nodes of urban and rural space are evaluated combined with the spatial distribution analysis of traffic demand levels. In villages and towns with large transportation needs, urban and rural bus trunk lines with high service density are arranged, and secondary bus trunk lines are laid out to connect urban and rural settlements. Low-frequency departure system or regular shifts are set to transport passengers to reduce the waste of public transportation resources. The trunk and branch lines of the above five types of bus line networks are coordinated and connected with each other, and at the same time, cooperate with the construction of stations to realize the networking of urban and rural bus lines.

The existing conventional bus in Wuxue City is the main component of the public transportation network, which meets the traffic needs of passengers within the urban area for medium and short distance travel, and undertakes the connection and transfer with the skeleton lines, roads and railways and other hubs. To improve the urban and rural public transport lines, first of all, on the premise of retaining most of the original urban and rural bus lines, on the basis of the modification of the road network structure, add new bus lines to the new roads and at the same time adjust some of the original lines that overlap with them, form a first-class urban and rural bus passenger line network, and establish passenger transport links between the central urban area and various urban areas and characteristic towns dominated by conventional public transport. Secondly, the bus branch line is mainly used as the connecting line of the main route to serve the interior of each street in the form of connecting rural residential areas. Relying on the three-level and four-level road network to plan bus

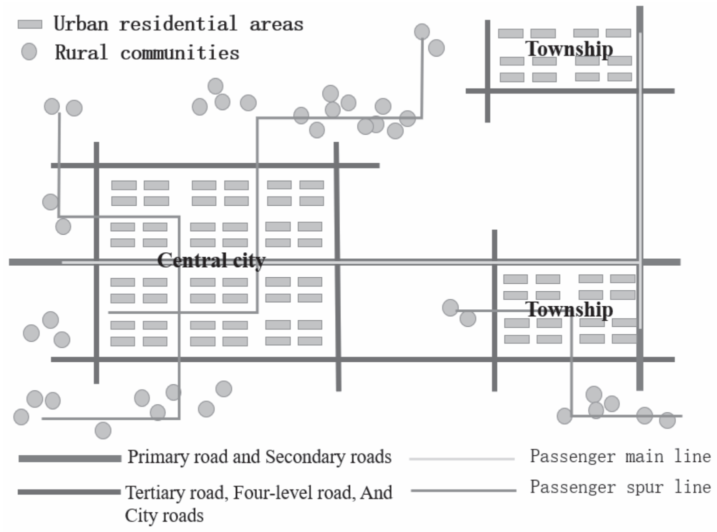

Fig. 10. Schematic diagram of urban and rural bus passenger lines.

Table 6. Comparison of urban and rural public transport before and after improvement.

Buffer range		Current status		Planning	Improvement
300m		28.03%		39.58%	11.55%
500m		41.33%		57.75%	16.42%

branch lines as supplementary lines for the conventional public transport system, form a secondary urban-rural bus passenger line network in urban and rural areas, connecting urban areas, rural communities and villages, with the branch line going deep into urban residential areas and remote residential areas in townships. By calculating the coverage of rural residential areas in the buffer zone with a bus line diameter of 300m and 500m of bus lines (Table 6), the accessibility of urban and rural bus stations is improved, thus further facilitating the travel and transfer of residents and making the sparse urban and rural areas more accessible. Considering the relatively lower road grade where the branch line is located and small passenger flow, small and medium-sized vehicles can be selected to enhance the vehicle service efficiency and maintain a certain economic benefit of the enterprise. At the same time, the rational layout of public transport hubs is conducive to improving operation benefit and transfer efficiency. According to the setting of different bus line networks, the public transport hub in Wuxue City can be divided into three categories: comprehensive bus hubs, general bus hubs, and rural public transport passenger flow distribution hubs, serving different objects respectively. Strengthening the construction of public transport hubs with different functions can help improve the entire urban and rural public transport system.

Conclusions

This paper proposed an approach of building a large urban-rural transportation network with different modes of transportation by using multi-source data including mobile phone data. The multi-mode planning of urban and rural transportation should combine the characteristics of various urban and rural transportation modes, coordinate various elements of urban and rural space according to the objective and actual traffic needs, comprehensively analyze multi-source data by using ArcGIS software, and identify the traffic demand space of urban-rural areas from the macro level. Taking Wuxue City as the research practice, it is found that with the support of complete data, the urban and rural traffic demand space can be analyzed and identified with quantitative data, which makes the traffic planning more scientific and accurate in line with the era of big data. Spatial identification of urban and rural traffic demand only serves as the technical means to assist multi-mode coordinated traffic planning, thereby for different urban and rural areas, differential analysis should be carried out in traffic planning in combination with the actual situation due to the difference in regional characteristics, so as to accurately implement urban and rural traffic multi-mode traffic planning.

Since the urban and rural space has basically formed a multi-mode transportation system dominated by roads and supplemented by railways, waterways and aviation. The traffic demand of Wuxue City presents the spatial characteristics of circular and nonlinear distribution. A multi-level traffic system can be established to coordinate the efficient transport of different modes of traffic. At the same time, this paper puts forward the division of labor planning strategies at different levels in the three aspects of comprehensive hub, road network structure and public transport, combined with urban and rural traffic information services, in order to reduce the waste of traffic resources and improve various traffic coordination, and furthermore, to set a good example for urban and rural traffic development in other similar areas. In a word, this paper aims to explore new methods of coordinated planning of urban and rural multi-mode transportation spatially, with a view to achieving better urban-rural integrated development.

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Conflict of Interest

The authors declare no conflict of interest.

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