Journal of Landscape Research 2026, 18(1-2): 13-17

Comprehensive Transportation Optimization Strategy of County Based on Collaborative Analysis with Production–Living–Ecology Spaces

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Abstract In order to enhance the coupling relationship between comprehensive transportation and functional space, and promote the high-quality development of counties, De'an County in Jiangxi Province is taken as an research object. A research framework of background assessment–problem identification–optimization improvement is applied to propose targeted optimization measures for the problems existing in the coordinated development of comprehensive transportation and production–living–ecology spaces. Research has shown that: (i) by constructing a transportation linkage model between the regional transportation circle and the county's industrial circle, it can not only improve the existing industrial operation efficiency and expand the industrial market, but also effectively promote the accelerated formation of industrial cluster in De'an County. (ii) By improving the urban transportation structure from three aspects: urban development guidance, internal traffic demand, and public transportation travel, it can comprehensively meet the mutual needs of people, transportation, and space, and effectively enhance the quality of urban development. (iii) It is an effective means to avoid resource waste, as well as an important measure to promote national spatial planning and maintain ecological spatial stability by proposing relevant requirements from three aspects: project level, engineering route selection, and protection measures.

Keywords Production–living–ecology spaces, Comprehensive transportation, County town, Urban and rural development

DOI 10.16785/j.issn 1943-989x.2026.1-2.003

County towns are important battlefields for promoting urbanization construction in China, as well as the core carriers for achieving high-quality development of urban-rural integration and promoting new urbanization. Production–living–ecology spaces, namely production space, living space, and ecological space, are the core carriers of national spatial functions and the basic support for spatial function operation and urban development. The synergy of the three is crucial for maintaining national spatial stability and building a high-quality urban development pattern. Urban comprehensive transportation is the core channel that supports the flow of urban and rural elements. It not only connects various functional spaces and coordinates spatial development contradictions, but also needs to solve the problem of collaborative adaptation with the production–living–ecology spaces[1]. Therefore, it is of great practical significance for promoting sustainable urban development by analyzing the contradiction between urban comprehensive transportation and the coordinated development with the production–living–ecology spaces and proposing optimization strategies.

Current research mainly focuses on large-scale regions such as the Weihe River basin[2], Yunnan border areas[3], and the Yinchuan metropolitan area[4]. There are also studies that evaluate the potential risks of regional territorial spatial development[5] and changes in habitat quality[6] by simulating the evolution of production–living–ecology spaces. At the level of planning strategy support, relevant research covers rural classification and recognition based on production–living–ecology spaces[7], beautiful rural construction[8], and optimization of county spatial pattern[9]. Existing research mostly focuses on the production–living–ecology spaces themselves or their supporting role in urban and rural development. It can provide new perspectives and references for optimizing urban spatial patterns by conducting collaborative analysis between the production–living–ecology spaces and urban comprehensive transportation and guiding transportation optimization.

In recent years, De'an County in Jiangxi Province has shown strong industrial development momentum. Located at the intersection of multiple transportation arteries, its urbanization process is rapid. However, there have also been problems such as a mismatch between development speed and infrastructure construction, and prominent contradictions between production construction and ecological protection. Based on this, this paper analyzes the coordinated development of comprehensive transportation and production–living–ecology spaces in county towns, identifies contradictions between various spaces and transportation development, and proposes targeted planning measures for optimizing and improving comprehensive transportation in county towns, in order to promote high-quality development of county towns.

1 Research methods

In this paper, a comprehensive transportation optimization framework for county towns is constructed, consisting of "background assessment–problem identification–optimization enhancement" (Fig.1). Firstly, a comprehensive transportation status assessment of the county and central urban areas is conducted to clarify the characteristics of the hierarchical transportation background. Then, based on the distribution and development characteristics of production, life, and ecological spaces, the prominent contradictions between the three types of spaces and the coordinated development of comprehensive transportation are identified. Finally, guided by problem, taking demand as the target, the comprehensive transportation layout is optimized, and the overall development quality of production–living–ecology spaces is improved.

2 Overview of the study area

De'an County is located in the northern part of Jiangxi Province, on the west bank of the Poyang Lake, at the southwest foot of the Lushan Mountain. It is adjacent to Lushan City (formerly Xingzi County) to the east, Yongxiu County to the south, Wuning County to the

Received: December 18, 2025 Accepted: January 26, 2026
Sponsored by the Science and Technology Research Project of Jiangxi Provincial Department of Education (GJJ2200758).

west, and Ruichang City and Chaisang District of Jiujiang City to the north. The total area of De'an County is about 858 km^2. As a key node in the vertical development axis of Nanchang-Jiujiang, De'an County has significant advantages in transportation location. De'an Station is set up across the Beijing–Kowloon Railway and Nanchang–Jiujiang Intercity Railway; the Fuzhou–Yinchuan Expressway, G105, and G316 respectively run through the east and west of De'an County; the Debai, Linbai and other highways connect urban and rural areas in an east-west direction, forming a transportation network that is smooth on the outside and interconnected on the inside.

3 Hierarchical comprehensive traffic background assessment

3.1 Current situation and evaluation of comprehensive transportation in counties

3.1.1 Status quo of regional transportation. The Beijing–Kowloon Railway (conventional freight) and the Nanchang–Jiujiang Intercity Railway (high-speed railway) run north–south through the De'an urban area, with a total length of 23 km. The G70 Fuzhou–Yinchuan Expressway passes through the area in a north–south direction, with a total length of 22.29 km.

3.1.2 Current situation of county-level highway transportation. There are three national highways within De'an County: G105, G316, and G532, connecting surrounding counties and cities, with a total length of 33.23 km. Provincial roads include S304 Debai Highway and S215 Changjiu Avenue: S304 is the main east–west transportation axis in De'an County, with a length of 43.36 km; S215 enters from the south side of Hedong Township and exits from the east side, with a length of 3.03 km; the total length of provincial roads is 46.38 km.

There are 12 county roads in De'an County, with a total mileage of 198.47 km, including 1 second-class highway with a total mileage of 5 km, 5 third-class highways with a total mileage of 98.43 km, 6 fourth-class highways with a total mileage of 95.05 km. There are 62 township roads, with a total mileage of 300.02 km, including 2 third-class highways with a total mileage of 8.235 km, and 49 fourth-class highways with a total mileage of 241.10 km.

3.1.3 Problems of comprehensive transportation in De'an County.

(1) Regional transportation is concentrated in the east and sparse in the west, dividing the urban space. The Beijing–Kowloon Railway, Nanchang–Jiujiang Intercity Railway, Fuzhou–Yinchuan Expressway (commonly known as Nanchang–Jiujiang Expressway in De'an County), G105, and G532 are concentrated on the eastern edge of De'an County and run from north to south. The east–west transportation relies excessively on the S304 Debai Highway, resulting in an imbalanced spatial distribution of the road network and a lack of a second channel connecting the hinterland of De'an County. The above-mentioned transportation arteries divide the urban area into four districts: Baota, Laocheng, Hedong, and Jiuxian. Most of the secondary roads are poorly connected, and the connections between the districts are weak, resulting in low urban operational efficiency.

(2) The density of the main line network is insufficient, with dense distribution in the east and sparse distribution in the west. According to the 2018 *Standards for Urban Comprehensive Transportation System Planning* by the Ministry of Housing and Urban–Rural Development, the density of the main road network in counties with a permanent population of less than 200 000 should reach 1.5–2.2 km/km^2. The total length of national and provincial highways in

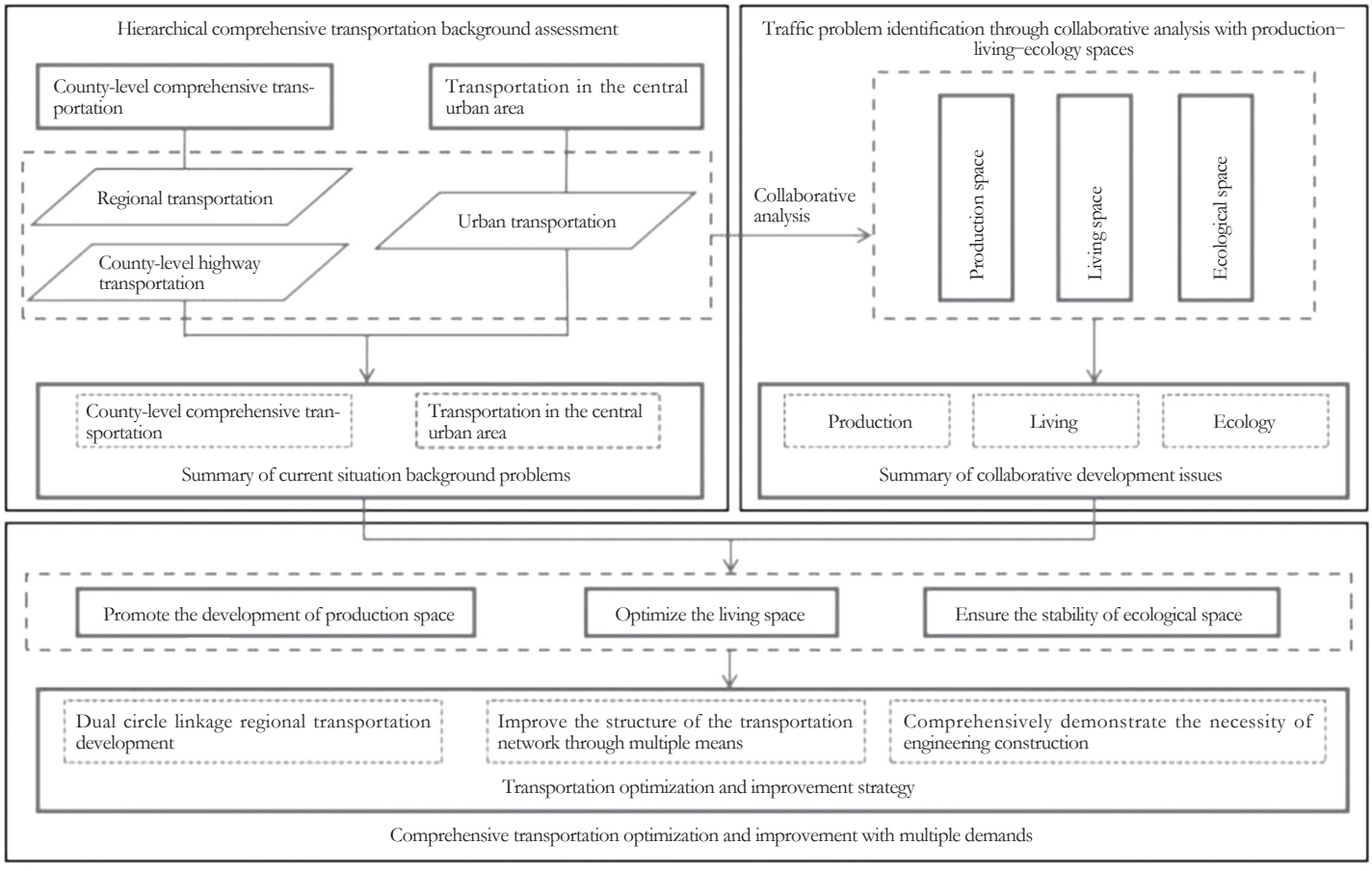

Fig.1 Research framework

De'an County is 79.61 km, and the density of the main road network is only 0.09 km/km^2, far below the standard specifications. At the same time, the road network in De'an County presents a pattern of "dense in the east and sparse in the west", with dense road construction in the southeast and significantly lower road network density in the west. The density of the main road network is insufficient, and it is dense in the east and sparse in the west.

3.2 Current situation and evaluation of transportation in the central urban area

3.2.1 Current situation of urban transportation. There are 17 main roads with a total length of 50.16 km, 39 secondary roads with a total length of 43.80 km, and 26 branch roads (open to traffic) with a total length of 13.13 km in the central urban area of De'an County (including Fenglin Industrial Park area).

3.2.2 Problems of urban transportation.

(1) The road network density is insufficient, and the proportion of levels is imbalanced. The total length of roads in the central urban area is 107.09 km, including 50.16 km of main roads, 43.81 km of secondary roads, and 13.12 km of branch roads. The construction land area of the central urban area is 36.20 km^2, and the density of main road network, secondary road network, and branch road network is 1.39, 1.21, and 0.36 km/km^2. The density of road network at each level does not meet the standard requirements. The mileage ratio of primary, secondary, and branch roads is 0.47 : 0.41 : 0.12, indicating a serious imbalance in the hierarchical structure.

(2) The road network structure is incomplete, and the traffic efficiency is limited. The backbone of the main roads in the central urban area is basically formed. But due to the interference of transit traffic, the system of distribution roads and residential roads is incomplete, and the traffic capacity is insufficient. Due to terrain limitations, there are many irregular intersections on main roads, and dead ends on branch roads are common, with poor microcirculation. During peak hours, traffic is excessively concentrated on main roads, which can lead to tidal congestion.

4 Traffic problem identification through collaborative analysis with production–living–ecology spaces

4.1 Collaborative analysis with production space

4.1.1 Current status of production space development. In terms of modern agriculture, De'an County is building multiple modern agricultural bases, but their spatial distribution is scattered. Part of the agricultural product bases that supply urban areas and exports are clustered around the urban area, with scattered layouts on the periphery, and it has not yet formed large-scale industrial clusters or development belts. The manufacturing industry is concentrated in the industrial parks in the south and north of the central urban area. The surrounding areas of De'an County are mainly dominated by industrial and mining industries, concentrated in central towns and villages, while the rest are scattered along the Debai Highway, lacking industrial agglomeration effects. The life service industry is concentrated in urban living spaces. The tourism industry shows the dispersed layout based on the resources. A small amount of tourism resources gather along the G316–X179 and X172–Debai Highway to the urban area, while the layout of other scenic spots is scattered, and it has not formed a systematic tourism route.

4.1.2 Problems with the coordinated development of production space.

(1) The road grade is low, and the accessibility of industrial resources is poor. The overall level of roads in De'an County is lower, and the proportion of fourth-class highway is high. The industrial distribution is strong in the east and weak in the west. The mineral resources in Wushan Town and Pengshan Forest Farm are concentrated, the surrounding roads are of low grade, and a ring road has not been formed. The development of resources is limited, and the spatial utilization rate is not high.

(2) The tourism supporting facilities are weak, and the road grades of the routes are insufficient. De'an County has abundant tourism resources, but the industrial system is not perfect, and the road connection is insufficient. The road level of tourist routes is relatively low, and the accessibility of some scenic spots is poor, resulting in insufficient utilization of resource benefits.

4.2 Collaborative analysis with living space

4.2.1 Current status of living space development. At the county level, Puting Town, located in the central urban area, has the highest population density, followed by Baota Township and Fenglin Town. The population density of other towns is relatively low, with most of the population located along the Fuzhou–Yinchuan Expressway and G316. At the same time, due to the influence of terrain and landforms, the population distribution shows a trend of low in the west and high in the east. The current urban construction land in the central urban area is 20.27 km^2, with a per capita urban construction land of 215.64 m^2. The area and proportion of various types of land use are shown as Table 1.

4.2.2 Problems with the coordinated development of living space.

(1) Road network layout is uneven, and urban development is unbalanced. The towns are distributed along the main transportation routes, with relatively concentrated in the southeast. The development level shows the characteristics of "high along national and provincial roads, high around urban areas, and low in the west". The Debai Highway connects towns such as Puting, Fenglin, and Nieqiao along the route; G105 covers Puting, Baota, and Hedong along the route; only Cheqiao Town is located along the G316 route, with insufficient radiation and driving. The level of transportation services in the western region is relatively low, and the scale of urban construction is relatively small.

(2) The proportion of road land is low, and the service level is insufficient. The proportion of land for roads and transportation facilities in the central urban area is only 8.92%, which is lower than the requirements of 10% to 25% in the 2011 *Code for Classification of Urban Land Use and Planning Standards of Development Land* by the Ministry of Housing and Urban–Rural Development, and the supply of transportation services is insufficient.

4.3 Collaborative analysis with ecological space

4.3.1 Current situation of ecological space distribution. In this paper, ecological protection

Table 1 Current construction land area in the central urban area of De'an County

Land use code	Land use name	Land use area km^2	Proportion of urban construction land//%
07	Residential land	5.52	27.22
08	Land for public management and public service facilities	1.67	8.25
09	Land for commercial service facilities	0.38	1.87
10	Industrial land	9.47	46.71
11	Land for logistics and warehousing	0.16	0.81
12	Land for roads and transportation facilities	1.81	8.92
13	Land for public facilities	0.24	1.20
14	Green space and square land	1.02	5.01
Total		20.27	100.00

red lines and nature reserves are defined as ecological spaces. The area of ecological protection red line in De'an County is 152.53 km^2, accounting for 17.76% of the area in De'an County, and involving 14 townships (towns, fields). The natural protected area covers an area of 20.25 km^2, accounting for 2.36% of the total area in De'an County, mainly distributed in Puting Town and Hedong Township.

4.3.2 Problems with the coordinated development of ecological space. The layout of county-level transportation facilities should prioritize avoiding ecological protection red lines and nature reserves. Point like facilities can be avoided and adjusted through site selection, while linear traffic arteries are difficult to completely avoid. The current situation is that some transportation facilities have encroached on the control area of ecological protection red line, occupying an area of 0.21 km^2, but they have not encroached on natural protected areas.

5 Comprehensive transportation optimization strategies with multiple demands

5.1 Regional transportation development of dual circle linkage: promoting the development of production space

5.1.1 Actively connecting with the development of regional transportation circles. The Nanchang metropolitan area plans to construct a comprehensive transportation network of "two rings and nine rays", with De'an County included as a key node in Ray 1 (Nanchang–Jiujiang Channel) and Ray 9 (Nanchang–Wuhan Channel). Ray 1 relies on Nanchang–Jiujiang High-speed Railway (planned), Nanchang–Jiujiang Intercity Railway, Beijing–Kowloon Railway, G70 Fuzhou-Yinchuan Expressway, etc.; Ray 9 relies on Wuhan–Jiujiang High-speed Railway, Xian Xiu Ji High–Speed Railway (planned), G70 Fuzhou–Yinchuan Expressway, S30 Yong'an–Wuping Expressway, G316, etc.

5.1.2 Accurately adapting to the construction of industrial circle within De'an County. Two east–west industrial axes are built based on S304, X172, and X179, respectively supporting the development of industrial and agricultural industries and tourism. By connecting G105 and G316 in series, an inner circle of industrial development is formed. It should adhere to the green ecological orientation, promote the transformation of traditional industries, cultivate emerging industries, develop the digital economy, promote industrial clustering, and build an industrial spatial pattern of "one core leading, two axis driven".

5.2 Improvement of transportation network structure by multi means: optimization of living space

5.2.1 Building a road system based on the development direction of urban areas. The land in the western and southern parts of the central urban area is becoming saturated. In the future, the focus will be on expanding towards the northeast direction, adopting an "inward aggregation" layout. It should strengthen north–south transportation connections, upgrade road grades or build new channels, and directly connect various areas, thereby supporting industrial development and residents' travel.

It should promote the integrated development of Gongqing–De'an–Yongxiu, extend Gong'an Avenue northward across the Boyang River, connect with G105 New National Highway and Changjiu Expressway Fenglin Interchange through Hedong District, create the main axis of north–south development of De'an–Gongqing, and open up the second channel connecting De'an County.

5.2.2 Improving the road network structure based on traffic demand forecasting. Adopting the technical path of "current traffic assessment–land supply research–travel demand forecasting", future traffic demand is assessed. It should sort out the current supply–demand contradiction, and evaluate the characteristics of land use, population, and travel; predict the traffic generation of newly added land use. Based on the current situation and new demand, peak hour traffic is converted, and a prediction model is constructed, to accurately identify road network shortcomings, and support road network optimization.

Firstly, based on the current traffic volume data and road network structure of De'an County, the areas where the traffic volume does not match the road network structure should be identified. It should evaluate the land use structure, population structure, travel modes, and travel destinations of the area, and comprehensively understand the reasons for the current problems. Subsequently, an investigation will be conducted on the supply of urban land, and effective predictions will be made on the newly added traffic volume, transportation modes, and travel destinations for this portion of land. Finally, based on the current traffic volume assessment and land supply situation, the traffic demand is divided into two levels: current optimization and future additions. After converting the car passenger coefficient and peak hour coefficient, they are matched to the constructed traffic travel prediction model to predict the peak hour traffic flow of each road in the future.

Based on peak hour traffic flow prediction in urban areas, it can accurately identify problems and their locations in the road network structure, providing reliable support for optimizing traffic and improving the road network.

5.2.3 Optimizing the public transportation system based on travel surveys. With the two-way development of De'an and Gongqing, and the increase of college students in Gongqing Science and Education City, the travel and exchange between citizens and students in the two places will further increase. Moreover, Jiuxianling Ecological Park in the south of De'an is one of the main gathering places for surrounding residents and students to travel and relax. Therefore, the Jiuxianling area of De'an plans to add an intercity bus route: from De'an County Bus Station to Gongqing Science and Education City, mainly passing through Yifeng Road, Baota Avenue, Dongfeng Avenue Railway Station Front Road, Gong'an Avenue, Gongqing City Railway Station Front Square, and Gongqing Science and Education City.

On the basis of the existing routes, three more bus routes will be built to serve the Baota area, Jiuxian area, and Fenglin area, continuously improving the coverage of bus network in the central urban area.

5.3 Comprehensive demonstration of the necessity of engineering construction: ensuring the stability of ecological space

5.3.1 Clearly defining the level of the construction project. In terms of provincial regional transportation construction, it is planned to build Nanchang-Jiujiang Expressway, which will pass through the eastern part of De'an County. At the same time, a new connection line between Yongxiu–Wuning Expressway and Duchang–Jiujiang Expressway will be built to run through the east and west of De'an County, and a highway interchange will be set up in Nieqiao Town. This type of high-speed construction project is a major project in the region and a provincial-level transportation construction project.

In terms of municipal highway construction, De'an County will build five connecting lines with the Changjiu Expressway, with an estimated mileage of 20 km and a scale of first-class highway. A new high-speed railway connection line from Wenhua Avenue to Lushan South Station is to be built, with the scale of first-class highway and the main node of Hedong.

To open up a western tourism route, it

should proactively connect with the West Sea of the Lushan Mountain, and tourists will be introduced from the West Sea to De'an via G316. It plans to upgrade and transform along the tourist routes, as a key project for upgrading county-level highways, G316–Cheqiao–Moxi-Nieqiao–Debai Highway–Fenglin–County Town–G105.

5.3.2 Optimizing the selection of key road routes. At the regional transportation level, for key construction projects with large spans and long distances within De'an County, a tripartite collaborative working mechanism should be established among the natural resources management department, engineering design department, and planning and design department. From the perspectives of management, design, and optimization, the impact of the project on residential areas should be reduced, the occupation of permanent basic farmland and cultivated land should be minimized, and the construction volume and economic investment should not fluctuate significantly.

5.3.3 Implementing ecological space protection. For ecological protection red lines and various ecological spaces, it should establish a three-level prevention and control system of "space avoidance–harmless crossing–ecological restoration". Firstly, ecological protection red lines and natural protected areas are used as the "veto items" for project route selection, supplemented by multiple scheme comparisons, with "avoidance priority" as the first choice. For sections that cannot be avoided and must be crossed, ecological disturbance can be minimized through engineering measures and pollution prevention measures. If necessary, biological channels can be opened up to reduce the impact.

6 Conclusions and discussion

Based on the current comprehensive transportation situation in De'an County, through collaborative analysis with the production–living–ecology spaces, various optimization measures and improvement methods for transportation development are proposed, effectively enhancing the correlation between transportation development and local functional space. The research shows that:

(1) By constructing a transportation linkage model between the regional transportation circle and the industrial circle in De'an County, firstly, it can improve the operational efficiency of existing industries and expand the industrial market, leveraging the advantages of existing transportation agglomeration. Secondly, it can effectively promote the further development of industrial space in De'an County and accelerate the formation of industrial clusters.

(2) By improving the urban transportation structure from three aspects: urban development guidance, internal traffic demand, and public transportation travel, it can comprehensively meet the mutual needs of people, transportation, and space, and effectively alleviate the many problems caused by regional traffic segmentation in De'an urban area.

(3) According to the requirements for project level, engineering route selection, and protection measures, it can not only strengthen the screening and selection of transportation construction projects within De'an County, but also ensure rigorous argumentation under multiple scheme comparisons, avoid resource waste. Ultimately, the protection measures are important for promoting national spatial planning and maintaining ecological spatial stability.

Although construction activities can be discussed and optimized from multiple perspectives, they are ultimately subjective activities guided by human intervention. The transportation development and production–living–ecology spaces of the county town are constantly facing dynamic adjustments in planning activities, so the focus of planning measures is on subsequent planning implementation, and it needs to strengthen planning management and ensure the relevant content of implementation in further research.

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