Development and Application of a Coupled Model for Rural-Transportation Coordination in China Based on an International Perspective

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Abstract. There has been a common phenomenon of rural population loss and rural development challenges throughout the process of industrialization and urbanization in developed countries, and these countries have implemented the rural revitalization strategy. As an important part of rural infrastructure, rural roads are critical to the success of rural revitalization. Rural roads in developed countries have been thoroughly built with the cooperative support of national and local governments. By developing a coupled model for rural-transportation coordination in developed countries and exploring the characteristic mechanisms of urbanization process and rural road development, the study establishes a coupled rural-transportation coordination model in China and makes a judgment on the development trend of rural roads in China. The findings demonstrate the requirement for long-term phased evolution and regional difference in the construction of rural roads within the context of rural revitalization, and the rural-transportation coupling coordination model can more accurately demonstrate the coordinated evolution of rural road scale and urbanization rate. Prior to 2035, it is anticipated that China's rural road network will continue to rise steadily along with the rate of urbanization and eventually stabilize.

Keywords: Rural roads · rural revitalization · urbanization · coordination analysis

1 Introduction

Rural roads are the most crucial or even the only mode of transportation and significant infrastructure in rural areas, and they are the fundamental and enabling conditions for rural revitalization. There are still issues with the development of rural roads in China, such as insufficient development scale, low service levels, and insufficient construction of supporting facilities. To better support rural development, China has implemented the "two-wheel drive" policy of rural revitalization and new urbanization, which will have a significant impact on rural road development. The construction of rural roads will also

help hasten the pace of rural revitalization. The degree of change in the coordination of rural development and rural road development in the continuous evolution can be scientifically revealed through the coupling coordination degree model, and it can also be used to explore the coupling interaction relationship between them. The model can give a quantitative analysis of the internal relationship between rural development and rural road development, as well as a decision-making basis for rural road planning departments.

County and township roads, local roads, rural roads, or low traffic volume roads, which belong to local road system or collector road system, are often used to describe the portion of the foreign road network that closely correlates to China's rural roads.

From a temporal perspective, developed countries are the first to enter a stable stage of rural road mileage. The scale of rural road networks in the United States, Germany, and Japan tended to stabilize in the 1970s. The United Kingdom and South Korea started large-scale construction in the 1970s and 1980s, and stabilized in the 1990s (Wu & Xu, 2022). In essence, these countries built an integrated urban and rural transportation network to establish smooth channels for various factors of production (Wang etc., 2022).

From the perspective of urbanization, Rural road construction and the urbanization process are closely related. In the middle of urbanization, between 30% and 70%, the scale of rural roads is in the stage of rapid growth, according to statistical analysis. In the late stages of urbanization, after 70%, the overall scale of the rural road network is essentially in a slow growth or relatively stable state, and some countries have even experienced a slight decline in rural roads (Wang, 2020). Consider the United States as an example. After extensive road network construction, the size of rural roads in the country peaked in the 1970s and 1980s, and from 1980 to 2017, as urbanization and the growth of small towns in the country progressed, the size of rural roads in the country decreased. Over the past forty years, the total mileage of rural roads in the United States has dropped from 477 km to 432 km, a decrease of 9.49%, and the proportion of the road network has decreased from 76.8% to 64.5% (Liu, 2022).

From the perspective of construction tasks, in developed countries, the size of rural road networks tends to stabilize after they reach the stage of all-around high-quality growth (Xi, 2017). The primary responsibility of countries started shifting away from large-scale building of rural roads and toward consideration of rural road standards, management, maintenance, security, and other factors (Xi, 2018). In general, under the background of "two-wheel drive", the ultimate achievement of effective coordination between rural areas and rural roads is a long-term stage evolution and spatial differentiation process.

2　Methodology

2.1　Indicator Selection

After carefully considering the four dimensions of economy, society, population, and transportation, the study is guided by the idea of "two-wheel drive" when choosing the indicators, and ultimately chooses two quantitative indicators of urbanization rate and rural road network scale to objectively reflect the urban-rural integration and the coordination status of urban-rural integration and rural road development.

Table 1. Coupling level classification criteria.

Degree of coupling	Grade	Coupling degree C-value interval
Low-level coupling	Level 1	[0,0.2]
Lower-level coupling	Level 2	(0.2,0.4]
Medium level coupling	Level 3	(0.4,0.6]
Higher-level of coupling	Level 4	(0.6,0.8]
High-level coupling	Level 5	(0.8,1]

2.2   Rural-Transportation Coupling Degree

The interaction between the level of urbanization and rural roads is a dynamic process that reflects the features of different phases of urban-rural development and has a significant influence on the growth and development of rural roads. The following calculation formula is used to build the coupled rural-transportation coordination model.

$$C = 2 \times \left\{ \frac{P \times R}{(P+R)^2} \right\}^{1/2} \tag{1}$$

Where: C is the coupling degree of urbanization level and coordinated development of rural roads, the value range of C is [0, 1], indicating the degree of interaction between the two, the larger the value of C indicates the stronger the interaction and mutual influence between urbanization rate and rural road scale; P is the rate of urbanization; R is the scale of rural roads.

The classification criteria for coupling degree C are shown in Table 1.

2.3   Rural-Transportation Coupling Coordination Degree

Although the degree of coupling can indicate the degree of interaction between the rate of urbanization and the size of rural roads, it cannot characterize whether the functions are highly supportive of one another or are minimally restrictive of one another. As a result, the study presents the coupling coordination index, which is derived as follows, to build a rural-transportation coupling coordination model.

$$D = \sqrt{C \times T}, T = \alpha P + \beta R \tag{2}$$

Where: C is the rural-transportation coupling degree, D is the rural-transportation coupling coordination degree. The urbanization rate and the rural road distance are thought to be equally important, according to expert reasoning, $\alpha = \beta = 0.5$.

The grading criteria for coupling coordination degree D are shown in Table 2.

Table 2. Classification criteria for coordination.

Degree of coordination	Grade	Coordination D value interval
Extreme disorder	Level 1	(0.0–0.1)
Severe disorder	Level 2	[0.1–0.2)
Moderate disorder	Level 3	[0.2–0.3)
Mild disorder	Level 4	[0.3–0.4)
On the verge of disorder	Level 5	[0.4–0.5)
Bare coordination	Level 6	[0.5–0.6)
Primary coordination	Level 7	[0.6–0.7)
Intermediate coordination	Level 8	[0.7–0.8)
Good coordination	Level 9	[0.8–0.9)
Quality coordination	Level 10	[0.9–1.0)

3   Results

3.1   Coupling Coordination Evaluation and Time Series Evolution Law in Developed Countries

The study built a coupled model for rural-transportation coordination for five developed countries—the US, Germany, the UK, South Korea, and Japan—and empirically examined the mechanism for dynamically promoting urbanization rate and rural road scale in those five developed countries over the course of the previous century.

According to the findings on coupling degree, there is a strong correlation between the development of rural road scale and urbanization rate, and the general level rises with coupling degree year after year.

In terms of time stages, early, the UK and Japan's coupling degree C-values in the 1950s and 1960s range between 0.5 and 0.7, displaying 3rd level medium and 4th level high coupling characteristics, indicating that the level of urbanization and the scale of rural roads start to work together; in the middle period, The C-values of the coupling degree for all five countries, from the 1970s to the 1990s, are between 0.9 and 1, indicating the fifth level of high coupling, indicating that the benign coupling between the rate of urbanization and the size of rural roads strengthens and gradually develops in the orderly direction; in the latter period, the benign resonant coupling between the level of urbanization and the scale of rural roads achieves and tends to a new orderly structure, starting in the 1990s, as indicated by the C-values of the coupling degree for the five countries tending to 1.

Regarding the degree of coordination, as shown in Fig. 1, the findings indicate that in five developed countries, the coupled degree of coordination of urbanization rate and rural road scale exhibits a progressive progression from serious disorder to high quality coordination development. The coordination degree of all countries with rural roads can reach the 7th level of intermediate coordination or higher when the urbanization rate reaches 70%, and it can reach the 10th level of high-quality coordination when
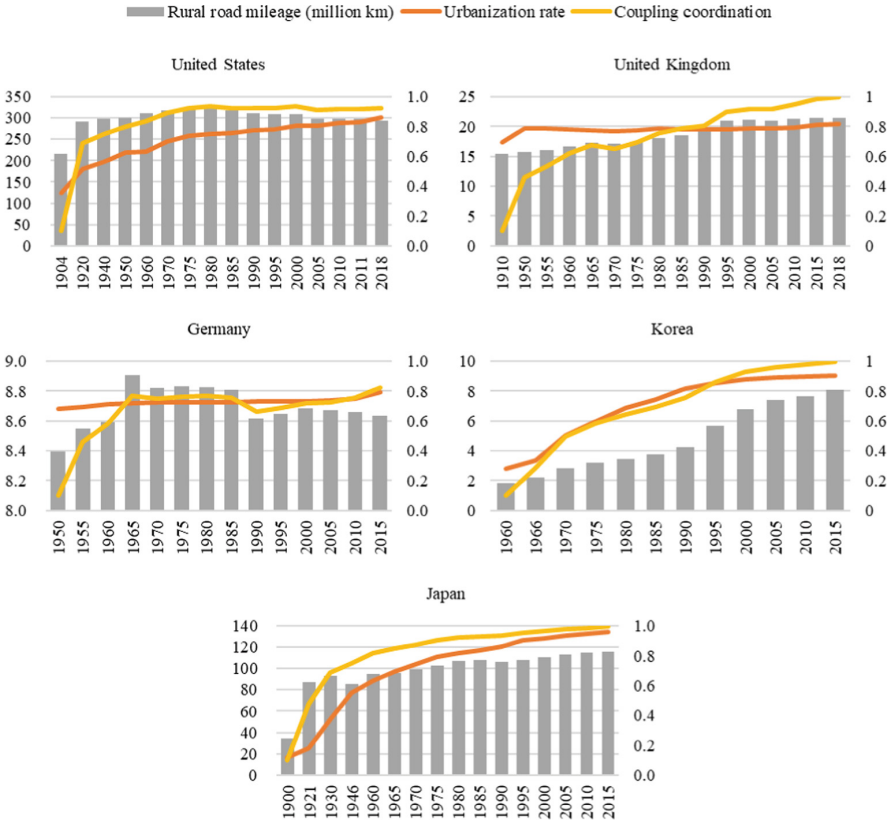
Fig. 1. Coupling coordination between urbanization rate and rural road scale in five developed countries

it reaches 80%, except for Germany, which reaches the 9th level of good coordination. Quantitative evidence shows that the overall scale of the rural road network is essentially in a condition of gradual growth or comparative stability when urbanization is in its late stages as opposed to the middle stages, when it is growing rapidly.

3.2 Analysis of Coupled Rural-Transportation Coordinated Development in China

A coupled rural-transportation coordination model was built in China, and quantitative assessment and analysis were done using data on urbanization rate and rural road scale from 1990 to 2020. The urbanization rate and rural road development in China exhibit high level coupling characteristics, and the coordination index rises year after year, reaching good coordination in 2010, and gradually advances in an orderly direction. In general, the model can better fit the stages of urbanization and rural road development in China.

The degree of coupling between China's urbanization rate and rural road scale is comparable to that of developed countries, and a high level of coupling was attained in the 1990s, signifying a significant interaction between the two indicators.

Prior to 2003, China's rural-transportation coupling coordination status was in a state of disorder in terms of coordination degree, with the 1990s being in a significant disorder and the 2000s being in a moderate disorder. From 2000 to 2003, the coordination status improved, which coincided with the large-scale construction and development stage of our country during that period. Following 2010, China entered a phase of urban-rural integration, the eradication of poverty, and rural revitalization, and the transportation system transitioned from one of "creating a moderately prosperous society" to "promoting the four good rural roads". Both the urbanization rate and the length of rural roads experienced significant expansion, and the model data at this point indicated that China's rural roads and urbanization levels had a solid working relationship, as shown in Fig. 2.

China has not yet reached the stage of high coordination of the growth of coordinated rural-transportation coupling, and there is still much space for improvement in China's rate of urbanization and the size of rural roads.

China is currently in the middle of its urbanization process; as a result, the rate of urbanization is accelerating, the rural to urban population shift is continuing, the distribution of the rural and urban population is profoundly altered, some traditional population settlements are gradually vanishing, and new gathering places are continuously emerging and expanding, which will have a significant effect on the size of the rural road network. Prior to 2035, China's rural road mileage would continue to rise with the urbanization rate and steady growth. By 2035, China's urbanization development is anticipated to gradually approach a mature phase.
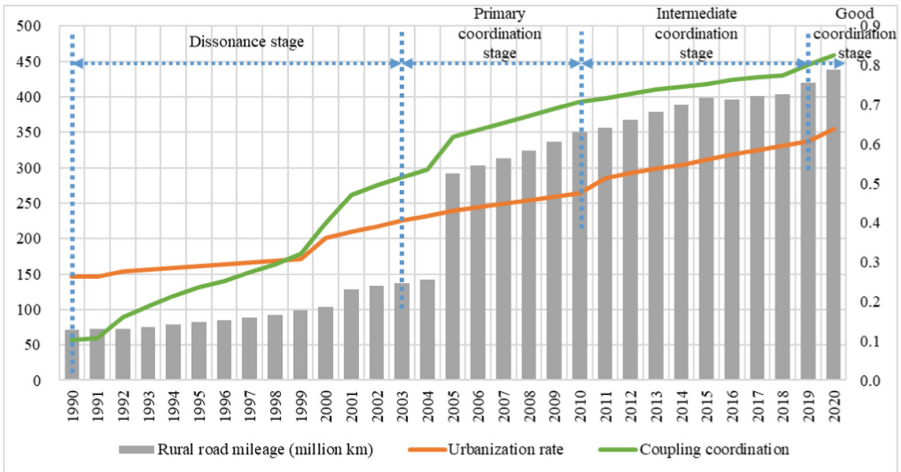

Fig. 2. Coupling and coordination of urbanization rate and rural road mileage in China

4   Conclusions

This study first provides an overview of the law of rural roads development in developed countries, after which it develops a coupled model for rural-transportation coordination and uses examples from developed nations to show how effective the model is. Finally, in accordance with China's national conditions, the study creates a coupled model for rural-transportation coordination, analyses the country's rural roads' current state of development, and forecasts its future development trends. These findings might serve as a guide for policymakers. The following conclusions are obtained from this study:

1. Under the background of "two-wheel drive", the coordination between rural and rural roads is a process of long-term phased evolution and spatial differentiation.
2. Data from many developed countries have verified that the evolution between rural and rural roads can be reflected by developing a coupling coordination degree model.
3. According to the coupling coordination model of rural and rural roads in China, the mileage of rural roads will continue to grow steadily with the increasing urbanization rate before 2035.

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