Land Transportation Accessibility and Urbanization Spatial Pattern Based on Coupling Coordination—Taking Chengdu-Chongqing Urban Agglomeration as an Example

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Abstract. Urbanization and transportation network construction influence and restrict each other. To explore the interaction between transportation development and urbanization spatial pattern, take the Chengdu-Chongqing urban agglomeration as an example to discuss the evolution relationship between land transportation accessibility and urbanization spatial pattern based on coupling coordination measurement model. The results show that the spatial distribution of urbanization level has typical characteristics of “core-periphery”. Besides, the accessibility of all kinds of land transportation presents a pattern of “central agglomeration” and “axis expansion”. The coupling coordination degree of the land transportation accessibility and urbanization is generally higher, and the western region is better than that of the eastern area. Specifically, coupling coordination degree between urbanization and high-speed railway/ordinary railway accessibility is higher in the west and lower in the east, while it opposite between urbanization and highway/land transportation accessibility, which is higher in the east and lower in the west.

Keywords: Urbanization; Land traffic; Accessibility; Coupling-coordination.

1. Introduction
Improving the accessibility of traffic and reducing the spatial distance are conducive to urbanization [1]. Urbanization development promotes transportation construction and improves transportation accessibility [2]. Traffic and urbanization influence each other, current discussions on transportation and urbanization development focus on: Wu used econometrics method to test the relationship between highway traffic and urbanization [3]; Wang texts the development of China’s transportation network affects the level of urbanization [4]; Xiong found that the development of urbanization was affected by the construction of traffic infrastructure [5]; Gutierrez demonstrated that construction of transportation infrastructure can promote the development of areas along the road [6]. Zhou found that there is a certain coupling relationship between urbanization and spatial distribution of traffic demand [7].
The coupling coordination degree theory reflects coupling degree and coordinated development of system. Chen used coupling coordination to analyze the development degree of transportation and urbanization [8]; Cui found spatial differences in coordination between high-speed traffic construction and land use efficiency [9]; Sun used the coupling coordination degree model to study the coordination relationship between China’s transportation and urbanization [10]; The above researches focus on the impact of transportation on urban development or the relationship between transportation and urbanization process. Accessibility reflects the degree of interaction between traffic and urban [11]. Therefore, it is significant to use the coupling coordination to analyze relationship, and to promote the coordinated development of traffic and urbanization.
Chengdu-Chongqing urban agglomeration has the fastest transportation network construction and the most mature development. It is selected as the object, the spatial interaction between traffic accessibility and urbanization is revealed through the coupling coordination model.

2. Methods

2.1. Calculation of Transportation Accessibility
Accessibility is related to location and traffic, affected by urban and economic level. Weighted average travel time $A_i$ is used to measure accessibility [12], the smaller of $A_i$, the better of traffic accessibility.

$$A_i = \frac{\sum_{j=1}^{n} T_{ij} \times M_{ij}}{\sum_{j=1}^{n} M_{ij}} = \sqrt{P_j \times G_j}$$  \hspace{1cm} (1)

Where, $T_{ij}$ is the time for minimum travel distance; $M_j$ is the comprehensive quality of the city, $P_j$ is the urban population and $G_j$ is the GDP of the city; $n$ is the number of cities.

2.2. Urbanization Measurement
15 indicators are selected to construct the urbanization index system, and the entropy method [13] is used to calculate the weight, as shown in Table 1.

| Criterion | Index                                                      | Weight |
|-----------|------------------------------------------------------------|--------|
| Population| Urbanization rate(%)                                       | 0.0103 |
|           | Urban population density(10000 people/m²)                  | 0.0286 |
|           | Proportion of non-agricultural employment population(%)    | 0.0214 |
|           | Proportion of built-up area to administrative area (%)     | 0.3926 |
|           | Per capita built up area(Square kilometers/10000 people)  | 0.0357 |
| Spatial   | Per capita GDP(100 million yuan/m²)                       | 0.0580 |
|           | Average investment in fixed assets(10000 yuan/ m²)        | 0.0299 |
| Social    | The number of beds in health institutions per 10000 people | 0.0049 |
|           | The number of doctors per ten thousand population          | 0.0043 |
|           | The number of middle school students per ten thousand population | 0.0391 |
|           | Proportion of secondary and tertiary industries (%)        | 0.1346 |
| Economic  | Per capita GDP(yuan)                                      | 0.0259 |
|           | Urban per capita disposable income(yuan)                   | 0.1696 |
|           | Green coverage rate of constructed areas (%)               | 0.0046 |
|           | Per capita cultivated land area(mu)                       | 0.0405 |

Establish a model to reflect the degree of urbanization level $Q_i$ [13].

$$Q_i = \sum_{j=1}^{n} W_i \times X_{ij}$$  \hspace{1cm} (2)

Where, $W_i$ is the weight of a single index. $X_{ij}$ is the standardized value of the index.

2.3. Coupling Coordination Degree Model
Coupling is the dynamic relationship of interdependence. The coupling model reflects the degree of correlation between traffic accessibility and urbanization [14]:

$$C = \left[ \frac{u_1 \times u_2}{(u_1 + u_2)^2} \right]^{1/2}$$  \hspace{1cm} (3)

$u_1$, $u_2$ are the standardized data of urbanization and traffic accessibility, $C$ is the coupling degree.

To better reflect the interactive coordination mechanism between urbanization and land transport accessibility, a coupled coordination model was developed:

$$D = \sqrt{C} \times \bar{T} = a u_1 + b u_2$$  \hspace{1cm} (4)

Where, $T$ is the evaluation index of transportation accessibility and urbanization; $a$, $b$ represent the contribution of transportation accessibility and urbanization, both taking 0.5 [15]. $D$ is the coupling coordination, taking the value range 0~1. It can be divided into extreme imbalance, serious imbalance, moderate imbalance, mild imbalance, on the verge of imbalance, barely coordination, primary coordination, intermediate coordination, good coordination and high-quality coordination.
3. Analysis of Results

3.1. The Land Transport Accessibility Patterns

Using formula (1) to calculate transportation accessibility, then visualized the results by IDW method of ArcGIS, as shown in Figure 1. Urban agglomeration space conforms to the "core-periphery" structure.

![Figure 1. Land transportation accessibility of Chengdu-Chongqing Urban Agglomeration.](image)

3.1.1. The characteristics of high-speed railway accessibility. From Figure 1(a), the spatial distribution is irregular. The gradient difference in the density of high-speed railway network leads to regional differences in accessibility. Accessibility value is 1.02-2.53, the average in Chongqing is 1.61h, Sichuan is 1.51h. The top 3 urban areas of the Chengdu-Chongqing urban agglomeration in terms of regional accessibility are Chongqing, Chengdu and Neijiang. The main urban area of Chongqing and Chengdu is the largest high-speed rail hub in the region, connected to the surrounding towns, the accessibility is relatively high; Neijiang is located in the geometric center of urban agglomeration with superior geographical conditions, convenient transportation and accessibility. The overall accessibility of the southeast region is low, such as Wanzhou and Dazhou are located on the edge of urban agglomeration.

3.1.2. The characteristics of ordinary railway accessibility. From Figure 1(b), the ordinary railway accessibility value is 1.76-6.84. The shortest accessibility is concentrated in central, the accessibility decreases as it expands outward from the central city. The most accessible cities are developed along trunk lines. Chongqing has many ordinary railway lines, gather most of chengdu-Chongqing transportation network, while Chengdu gathers sichuan's ordinary railway network. The accessibility of northern Sichuan is better than the south. Due to the convenient connection between the northern region and Chongqing's ordinary railway network, the level of accessibility is improved under the interaction between cities, while the southern city relies on the urban belts to drive the vertical development trend of the north, lacking the direct connection with the districts.

3.1.3. The characteristics of highway accessibility. In Figure 1(c), the distribution of characteristics is more balanced. It decreases from the main urban area to the peripheral areas and counties, which is in line with the distance attenuation characteristics, the overall distribution is irregular and annular. The highway accessibility is 2.12-6.22, the average in Chongqing is 3.37h, Sichuan Province is 3.18h. The road foundation in Chongqing is good, a radial road network is formed by several main arteries. Hechuan, Tongliang and other cities are close to the main area and have convenient transportation due to the driving effect of the main urban area. Wanzhou, Kaizhou, Qianjiang, Yunyang and other cities are far away from the main urban area of Chongqing, with poor accessibility. Sichuan is better than Chongqing, and the accessibility value in Chengdu is the lowest. The surrounding cities such as Suining, Ziyang and Neijiang are convenient, while the marginal cities such as Dazhou and Ya’an are inconvenient.

3.2. The Distribution Pattern of Urbanization

Use the formula (2), get the results of the urbanization development level of each city in the Chengdu-Chongqing urban agglomeration. And based on the ArcGIS 10.2, the visualization is shown in Figure 2.
Figure 2. The urbanization level of urban agglomeration. Spatial pattern of urbanization has the characteristics of "core-periphery". The urbanization level of Chengdu-Chongqing urban agglomeration ranged from 0.19 to 0.65. The higher-level areas accounted for 11.1%, mainly concentrated in the small circle with Chengdu and Chongqing as the main urban areas. There are 10 relatively high level regions, most of them are located in areas connected to higher-level areas and are affected by the positive spatial spillover of high-level urbanization. Relatively middle-level areas accounted for 22.2%, which are widely distributed, but most of them are peripheral areas bordering relatively high and medium-high areas; middle and low areas account for 19.4%, The level of urbanization is slightly lower, distributed in the middle and east of the urban agglomeration. Relatively low-level areas are scattered and located on the periphery of urban agglomerations.

3.3. The Coupling Coordination Degree between Land Traffic Accessibility and Urbanization

Based on formulas (3)-(4), the urban agglomeration's transportation accessibility and urbanization coupling coordination degree are obtained, as shown in Figure 3.

Figure 3. Coupling coordination pattern of land transportation accessibility and urbanization.

3.3.1. The coupling coordination pattern between high-speed railway accessibility and urbanization. In Figure 3(a), the spatial differentiation is obvious. Coupling coordination degree is between 0.1-0.9, average value is 0.537, barely balanced. 27.8% of the regions have a serious imbalance. Chongqing is 0.476, on the verge of imbalance. 13 cities with \( D \geq 0.5 \), distributed around the main urban area of Chongqing. 8 areas with the worst coupling and coordination, they have no high-speed rail lines open. The degree in Sichuan is 0.623, in the primary coordination range. Deyang, Mianyang are affected by the spatial spillover effect of the high level of urbanization in Chengdu, in the middle level of coordination. Suining, Neijiang and Meishan surrounding the core area are well-coupled and coordinated, and belong to the primary coordination state. Ya'an is in a mildly dysfunctional class with good high-speed rail accessibility. Zigong and Luzhou have the lowest coupling coordination value.

3.3.2. The coupling coordination pattern between ordinary railway accessibility and urbanization. In Figure 3(b), the average value is 0.507, barely coordinated. Chongqing is 0.428, on verge of imbalance. 47.6% of the cities with \( D \geq 0.5 \). The areas with the best coupling and coordination in Chongqing are Yongchuan and Wanzhou, which are well coordinated. Bishan, Tongliang, Qijiang etc are located on the edge of Chongqing. There is no ordinary railway line open to traffic. The coupling coordination level are seriously out of balance. Fengdu has no ordinary railway lines are opened to traffic, the degree is extremely out of balance. The average coupling coordination degree of Sichuan is 0.618, is the primary coordination level. Zigong has the best coupling coordination. Except for Ya'an and Luzhou, 13 areas have \( D \geq 0.5 \), more coordinated. Ya'an has special geographical conditions, is extremely unbalanced.
3.3.3. Coupling analysis of highway accessibility and urbanization coupling. In Figure 3c, the coupling coordination degree is 0.3-0.9, average value is 0.555, barely coordinated. 24 areas have a coupling coordination degree greater than 0.5; 3 areas with the lowest coupling coordination degree, are slightly out of balance. Chongqing is 0.556, barely coordinated. Wanzhou has good coupling coordination, followed by Fuling at the intermediate level of coordination. The development levels of Hechuan, Dianjiang, Nanchu are on the verge of imbalance. Sichuan is 0.554, barely coordinated. Dazhou belongs to intermediate coordination. 12 cities with D ≥ 0.5, accounting for 80% of Sichuan, are relatively balanced. The urbanization of Ya'an is poor, and road network is underdeveloped. The two are slightly out of balance. Suining and Ziyang are located in the center of the urban agglomeration, have good accessibility, but the urbanization is poor. The development of the two is on the verge of imbalance.

3.3.4. Coupling analysis of comprehensive accessibility of land transportation and urbanization. Analyze the coupling coordination between the comprehensive accessibility of land transportation and urbanization, as shown in Figure 4. In Figure 4a, the cities along the Chengdu-Chongqing line have dense traffic and good accessibility, with a pattern of "centralized gathering" and "axial expansion".

![Figure 4](image)

**Figure 4.** Coupling coordination of comprehensive land transport accessibility and urbanization. From Figure 4b, the coupling coordination degree is between 0.3-0.9. The mean value is 0.617, indicating primary coordination. 75% regional degree is greater than 0.5. The average coupling coordination degree in Chongqing is 0.599, barely coordinated. Wanzhou and Fuling are well coordinated, they are also the districts and counties with the best coupling coordination in the urban agglomeration. The coupling coordination of Qijiang, Dianjiang, Fengdu, Tongnan, Nanchuan and Chongqing's main urban area is on the verge of maladjustment. The average degree in Sichuan is 0.643, which is primary coordination. Dazhou, Yibin, Zigong and Mianyang are intermediate coordination. Degree of 14 cities is higher than 0.5, accounting for 93.3% of the total. Ya'an comprehensive traffic construction level exceeded its urbanization construction, the development of the two slight imbalance.

4. Conclusions and Recommendations

To measure spatial interaction of urban agglomerations, the following conclusions are drawn:

*The coupling coordination of traffic-urbanization is affected by core cities and main traffic lines.*

The coupling and coordination of traffic accessibility and urbanization are affected by core cities and major transportation lines. In areas adjacent to core cities, coupling coordination is at a relatively high level. Affected by the traffic axis, the coupling coordination weakens as the distance increases.

*The construction of comprehensive transportation network can promote the development of "pole-core" urbanization.* The land network has a positive effect on the high-quality development of urbanization. The high-grade road network changes the land along the route, provides a new polar core for urban development, and promotes the development of urbanization spatial pattern.

*Core cities play an active role in promoting the urbanization development of surrounding cities.* The construction of transportation is conducive to giving play to the leading role of core cities, forming a transportation access circle and high-quality urbanization development circle centered on core cities, and enabling transportation networks and urbanization the spatial pattern is showing a positive development momentum of "point to surface".

Based on this, in order to solve the problem of the interactive development of land transportation and urbanization, suggestions are proposed as follows:

*Strengthen the complementary and linked development of cities and towns within the urban agglomeration.* Break through the boundaries of administrative divisions between towns and enhance...
the interaction between towns. Building central city, enhance the role of radiation, develop node towns, accelerate the urbanization of second and third-tier cities, and improve the urbanization system. 

Promote the development of transportation infrastructure in the periphery of the region. Accelerate the development of the transportation network, improve the accessibility of marginal cities and towns. Build a "radiation + circle layer" transportation network, and promote the construction of marginal towns; strengthen the transportation network connection between the marginal and core cities.

Strengthen the construction of "axle-radiating" regional traffic network structure. Based on the "Chengyu Urban Agglomeration Development Plan", construct a "shaft-spoke" transportation network to improve regional traffic accessibility. Construct two national comprehensive transportation hubs between Chongqing and Chongqing, enhance the integration level of transportation hubs.

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