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Evaluation of Transportation Corridor Service Capacity in Wuhan Metropolitan Area Based on a Five-Dimensional Framework

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Abstract: *The transportation corridor of the Wuhan Metropolitan Area serves as the core carrier for regional coordinated development, and its service capacity directly affects the metropolitan area's integration process. This paper constructs an evaluation index system for transportation corridor service capacity from five dimensions: infrastructure, transport service, safety, economic benefit, and environmental impact. Based on panel data from 2021 to 2023, descriptive statistics and Pearson correlation analysis are employed for empirical evaluation. The findings are as follows: ① Infrastructure scale has continuously expanded, with increasing mileage of highways, railways, and rail transit; ② Transport services show a "V-shaped" recovery, with passenger and freight volumes in 2023 rebounding significantly from the previous year; ③ Freight turnover is significantly positively correlated with total social logistics volume ($r = 0.999$, $p < 0.05$), revealing that the logistics industry still relies on an extensive development model of "volume for value" and economies of scale have not been fully realized; ④ Environmental impact is generally controllable, with vegetation area increasing year by year, though acoustic environment quality fluctuates. The study indicates that the transportation corridor of the Wuhan Metropolitan Area exhibits a structural characteristic of "infrastructure first, efficiency lag". Service capacity improvement should be promoted from three levels: functional integration, network integration, and operational integration, driving the logistics industry to transform from scale expansion to efficiency-driven growth.*

Keywords: *transportation corridor; service capacity; five-dimensional framework; Wuhan Metropolitan Area*

1. Introduction

As the main engine of Hubei Province's regional development layout, the Wuhan Metropolitan Area aims to become a major national growth pole, a green development demonstration zone of the Yangtze River Economic Belt, and an internationally influential science and technology innovation center. The transportation corridor of the Wuhan Metropolitan Area is the core carrier for achieving this development breakthrough, covering highways, aviation, railways, and waterways.

As the skeletal system of urban agglomeration spatial organization, the theoretical connotation of transportation corridors has evolved from a "collection of facilities" to a "functional system." Zou Wenbo (2023) pointed out that the integrated development of multi-level rail transit has become a major trend in China's rail transit system development. Coordination at three levels—functional integration, network integration, and operational integration—can effectively support regional economic integration [1]. Wang Deli (2023) further proposed that suburban railways are rapid rail transit systems connecting central urban areas with surrounding towns, effectively shortening travel time and expanding urban development frameworks, and are necessary for constructing a "1-hour commuting circle" in metropolitan areas [2]. In terms of evaluation methodology, Wang Chengfang et al. (2025) extended the Node-Place (N-P) model from the station scale to the corridor scale, identifying development states such as "unbalanced node," "unbalanced place," "dependent," and "balanced," providing a theoretical basis for differentiated development strategies of rail transit corridors [3].

Reviewing existing studies, the influence mechanism of multi-level rail transit integration on regional economic integration has been fully discussed, and the guiding role of suburban railways in the spatial restructuring of commuting circles has also been empirically tested. However, most existing studies focus on a single mode of transport (e.g., suburban railways, subways) or a single evaluation

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dimension, lacking a multi-dimensional, systematic evaluation framework for the service capacity of comprehensive transportation corridors in metropolitan areas. Drawing on the theoretical perspectives and methodological insights of the above studies, this paper constructs an evaluation index system from five dimensions (infrastructure–transport service–safety–economic benefit–environmental impact), takes the Wuhan Metropolitan Area as the empirical object, quantitatively assesses its transportation corridor service capacity, identifies weak dimensions, and proposes optimization strategies.

2. Construction of a Five-Dimensional Evaluation Index System

2.1 Theoretical Foundations of the Five Dimensions

The five-dimensional evaluation framework—"infrastructure, transport service, safety, economic benefit, environmental impact"—integrates core ideas from transportation corridor theory, the Node-Place model, and sustainable development theory.

(1) The "Point-Network-Flow-Area" four-phase coupling theory of transportation corridors. As the skeleton of urban agglomeration spatial organization, the service capacity of a transportation corridor depends on the synergy of transport hubs (point), infrastructure networks (network), passenger and freight flows (flow), and urban-rural territorial systems (area). In the five dimensions of this paper, infrastructure corresponds to "network," transport service corresponds to "flow," economic benefit and safety correspond to the development quality of "area," and environmental impact constitutes the sustainable boundary of "area".

(2) The Node-Place (N-P) model. Bertolini (1996) emphasized that transport stations have dual attributes: "node"(transport connectivity) and "place" (urban function agglomeration) [4]. The balance between the two is key to the healthy development of transportation corridors. This paper extends this logic from the station scale to the corridor scale: infrastructure and transport service reflect the "node" attribute, economic benefit and safety reflect the "place" attribute, and environmental impact provides constraints for balancing the two.

Complementary to the Node-Place model, the Transit-Oriented Development (TOD) theory proposed by Calthorpe (1993) emphasizes that transportation corridors serve as the critical backbone for connecting regional growth poles and organizing urban spatial structure. This theory provides a planning methodology for achieving integrated land-use and transport development at both the station and corridor scales, which underpins the rationale for selecting "economic benefit" and "environmental impact" as key evaluation dimensions in this study [5].

(3) The triple bottom line theory of sustainable development. Economic viability, social equity, and environmental protection are the three pillars of sustainable development. In the five dimensions of this paper, economic benefit corresponds to the economic dimension, transport service and safety correspond to the social dimension (residents' travel needs and safety guarantees), and environmental impact corresponds to the ecological dimension, forming an "economy-society-environment" tripartite coupled evaluation structure.

2.2 Logical Relationships among the Five Dimensions

The five dimensions are not simply together but have a hierarchical linkage of "foundation–carrier–goal–constraint" (see Figure 1):

(1) Infrastructure is the material foundation of corridor service capacity, determining the potential upper limit of transport service supply;

(2) Transport service is the core carrier of functional realization, converting the static capacity of infrastructure into dynamic passenger and freight flows;

(3) Economic benefit is the core goal of corridor construction, as improved transport service ultimately serves regional economic development;

(4) Safety is the bottom-line guarantee of operation; no dimension can be improved at the expense of safety;

(5) Environmental impact is the sustainability constraint of development, requiring that corridor growth does not exceed ecological carrying capacity.

There is also a "short board effect" among the five dimensions—a severe lag in any single dimension will constrain the overall service capacity improvement. For example, infrastructure expansion that does not match actual demand for transport service will lead to idle resources; growth in total logistics volume accompanied by environmental degradation is unsustainable.

As shown in Figure 1, infrastructure (highways, railways, rail transit, buses) lies at the foundation layer, determining the supply ceiling of transport service; transport service (passenger/freight volume, turnover) lies at the carrier layer, converting infrastructure capacity into actual flows; economic benefit (total social logistics volume, employment, land price) lies at the goal layer, the ultimate purpose of corridor construction; safety (casualty rate, facility integrity) and environmental impact (noise, air quality, vegetation) lie at the constraint layer, constituting the bottom-line guarantee of operation and the sustainable boundary of development, respectively. Economic benefit feeds back into infrastructure construction through reinvestment, forming a closed loop. A lag in any dimension may constrain the overall service capacity.

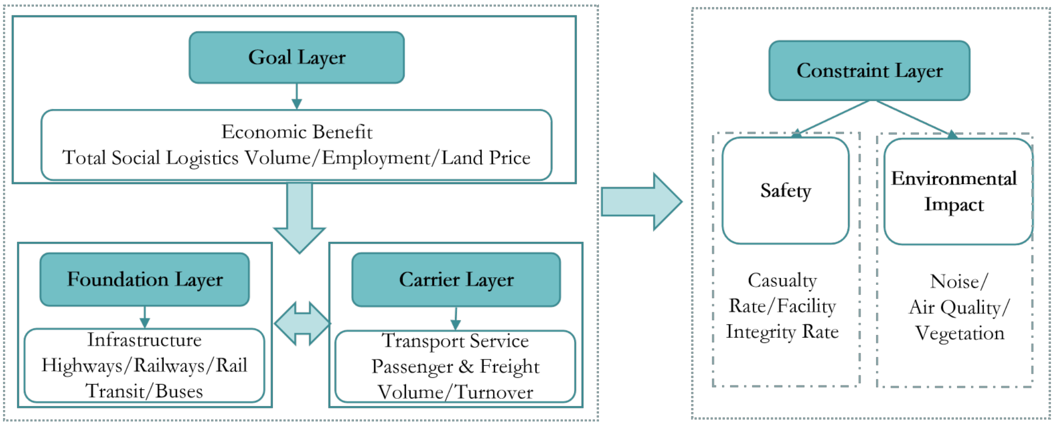

Figure 1 Logical relationships among the five dimensions

2.3 Construction of the Evaluation Index System

Based on the five elements of transportation corridor service capacity in the Wuhan Metropolitan Area—infrastructure, transport capacity, service quality, intelligence and informationization, and environmental sustainability—this paper constructs an index system covering 5 dimensions, 2 levels, and 19 specific indicators. The components of the system are not only parallel but also internally complementary. Table 1 lists the specific indicators and their names.

Table 1 Construction of Service Capability Evaluation Indicators for Transportation Corridors in the Wuhan Metropolitan Area

Primary Indicator	Secondary Indicator
Traffic Infrastructure Construction	Highway Mileage, Railway Operating Mileage, Rail Transit Line Length, Total Length of Public Bus and Tram Lines
Transportation Services	Passenger Traffic Volume, Freight Traffic Volume, Passenger Turnover, Freight Turnover
Traffic Safety	Casualty Rate, Road Facility Integrity Rate, Safety Protection Facility Allocation Rate, Traffic Violation Rate
Economic Benefits	Total Social Logistics Volume, Direct Employment Number, Land Price Increase Rate Along the Corridor
Environmental Impact	Air Quality Compliance Rate, Average Daytime Traffic Noise, Good and Better Rate of Daytime Road Traffic Sound Environment Quality, Vegetation Area

3. Empirical Analysis of Service Capacity of Traffic Corridors in Wuhan Urban Agglomeration

Based on the traffic corridor service capacity evaluation index system, this section focuses on the analysis of traffic infrastructure, transportation services, environmental impact and economic benefits.

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Based on the actual situation of the traffic corridors in Wuhan Urban Agglomeration, by collecting relevant indicator data, combined with the above dimensions and specific indicators, statistical analysis and other methods are used to comprehensively evaluate the current situation and existing problems of the traffic corridor service capacity.

3.1 Data Collection

The selected indicators are mainly quantitative indicators. After screening, statistical indicators that are available and have the possibility of horizontal comparison are determined. For some indicators that can directly reflect the service capacity of traffic corridors but cannot be directly quantified or are difficult to obtain data, such as the indirect employment benefits driven by traffic corridors, logistics value-added, transportation tool load factor, traffic congestion index, etc., they are not listed.

3.1.1 Infrastructure

The infrastructure construction of the traffic corridors in Wuhan Urban Agglomeration is mainly reflected by the traffic line mileage. Analyzing the change data of these mileage can directly reflect the impact of infrastructure construction on the service capacity of the traffic corridors in Wuhan Urban Agglomeration. The data on highway, railway mileage, rail transit and total length of public bus and tram lines are shown in Table 2.

Table 2 Infrastructure Data of Transportation Corridors in Wuhan Metropolitan Area

Indicators	Unit	2021	2022	2023
Total Highway Operating Mileage	Km	16660.7	16637.61	16800.51
Total Railway Operating Mileage	Km	860.7	874.9	948.8
Rail Transit Line Length	Km	484.2	504.2	529.62
Total Length of Public Bus and Tram Lines	Km	13032.1	13779.8	13698.5

Data Source: Wuhan Comprehensive Transportation Annual Development Report/www.whzhjty.com

The table reveals that the infrastructure scale of transportation corridors in the Wuhan Metropolitan Area has been expanding annually, with various transport routes continuously extending. The total highway mileage increased from 16,660.7 kilometers in 2021 to 16,800.51 kilometers in 2023. Railway mileage rose from 860.7 kilometers in 2021 to 874.9 kilometers in 2022, further reaching 948.8 kilometers in 2023. Urban rail transit lines extended from 484.2 kilometers in 2021 to 504.2 kilometers in 2022, and reached 529.62 kilometers in 2023. Public bus and trolleybus routes also grew from 13,032.1 kilometers in 2021 to 13,698.5 kilometers. The optimization of transportation infrastructure has not only facilitated residents' mobility within the metropolitan area but also effectively alleviated traffic congestion. The more comprehensive and extensive the transportation facilities, the more prominent their service capabilities naturally become.

3.1.2 Transportation Services

The transportation service level of the Wuhan Metropolitan Area's transport corridors is primarily reflected through passenger and freight volumes as well as passenger and cargo turnover rates. Analysis of the trends in these quantitative data can clearly demonstrate the historical development of transportation service capabilities. Specific data are detailed in Table 3.

Table 3 Transport Service Data of Traffic Corridors in Wuhan Metropolitan Area

Indicators	Unit	2019	2020	2021	2022	2023
Passenger Traffic Volume	10,000 Person-times	25516.37	10656.08	6945.95	4667.1	9924.01
Freight Traffic Volume	10,000 Tons	67555.22	52686.12	63555.88	61524.66	71299.69
Passenger Turnover	10,000 Person-km	1243.32	582.94	249.12	159.24	356.16
Freight Turnover	10,000 Ton-km	3897.17	3081.58	2312.47	2686.38	3010.77

Data Source: 2024 Wuhan Statistical Yearbook/tjj.wuhan.gov.cn.

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The table reveals that passenger traffic volume in the Wuhan Metropolitan Area's transportation corridor declined from 255.16 million in 2019 to 46.67 million in 2022, showing an overall downward trend before rebounding to 99.24 million in 2023. Freight traffic exhibited fluctuating patterns, likely influenced by demand variations, traffic congestion, or weather conditions. Passenger turnover decreased from 12.43 million km/h in 2019 to 1.5924 million km/h in 2022, recovering to 3.5616 million km/h in 2023. Freight turnover dropped from 38.97 million tons/km in 2019 to 23.1247 million tons/km in 2021, then steadily increased through 2022 and 2023 before reaching 30.1077 million tons/km. These data indicate incomplete service capacity in the corridor, requiring gradual optimization in demand forecasting and traffic management strategies.

3.1.3 Environmental Impact

The environmental impact of the traffic corridors in Wuhan Urban Agglomeration is mainly reflected by factors such as traffic noise and vegetation area. The data on the average daytime traffic noise, the good and better rate of daytime road traffic sound environment quality and the vegetation area are listed in Table 4.

Table 4 Environmental Impact of Transportation Corridors in the Wuhan Metropolitan Area

Indicators	Unit	2019	2020	2021	2022	2023
Average Daytime Traffic Noise	db	68.7	68.1	71	69.3	69.7
Good and Better Rate of Daytime Road Traffic Sound Environment Quality	%	/	/	36.1	74.6	50.7
Vegetation Area	Hectare	29035.16	29685.16	30687.96	31689.09	32694.49

Data Source: Wuhan Municipal Bureau of Ecology and Environment/hbj.wuhan.gov.cn and Wuhan Municipal Bureau of Gardens and Forestry/ylj.wuhan.gov.cn.

The table reveals that traffic noise averages show minimal fluctuations and demonstrate stable trends, while the proportions of good and relatively good traffic acoustic environment quality exhibit significant volatility. Notably, vegetation coverage has maintained a consistent annual growth trajectory, expanding from 29,035.16 hectares in 2019 to 32,694.49 hectares by 2023. Through comprehensive analysis of noise levels, acoustic environment quality metrics, and vegetation coverage during the development and utilization of traffic corridors, it is conclusively demonstrated that corridor expansion exerts limited environmental impacts.

3.1.4 Economic Benefits

The economic benefits of the traffic corridors in Wuhan Urban Agglomeration are mainly reflected by the total social logistics volume index. Analyzing the change data of this index can directly reflect the economic contribution of the traffic corridors to Wuhan Urban Agglomeration. The annual data of total social logistics volume are shown in Table 5.

Table 5 Economic Benefits of Transportation Corridors in the Wuhan Metropolitan Area

Indicators	Unit	2021	2022	2023
Total Social Logistics Volume	100 Million Yuan	42826.48	45769.16	48050.77

Data Source: Wuhan Comprehensive Transportation Annual Development Report/www.whzhjty.com.

The table shows that logistics demand has maintained steady growth, rising from 4.282648 trillion yuan in 2021 to 4.805077 trillion yuan in 2023. However, the growth rate in 2023 declined by 1.9 percentage points compared to 2022. This slowdown reflects the stabilization of logistics expansion amid economic recovery, likely driven by increasingly robust transportation infrastructure and growing residential and industrial demands.

3.2 Analysis Methods

3.2.1 Selection of Analysis Methods

This paper uses SPSS software to analyze and evaluate the current situation and problems of the service capacity of traffic corridors in Wuhan Urban Agglomeration.

3.2.2 Application of Analysis Methods

Linear data from 2021 to 2023 are selected for time matching. Pearson correlation coefficient is

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used to test the linear correlation strength between traffic indicators and transportation service indicators, as shown in Table 6.

Table 6 Data on Total Highway Length in Operation and Passenger/Freight Traffic Volume

		Z-scoreTotal Highway Operating Mileage	Z-scorePassenger Traffic Volume	Z-scoreFreight Traffic Volume
Z-score Total Highway Operating Mileage	Pearson Correlation	1	0.951	0.998*
	Sig. (2-tailed)		0.201	0.043
	N	3	3	3
Z-score Passenger Traffic Volume	Pearson Correlation	0.951	1	0.969
	Sig. (2-tailed)	0.201		0.158
	N	3	3	3
Z-score Freight Traffic Volume	Pearson Correlation	0.998*	0.969	1
	Sig. (2-tailed)	0.043	0.158	
	N	3	3	3

The table reveals that the total highway mileage exhibits positive correlations with passenger traffic volume ($r=0.951$) and freight volume ($r=0.998^*$; $p<0.05$), indicating that increased highway mileage drives growth in transportation services. Notably, the Pearson correlation coefficient between total highway mileage and freight volume reaches 0.999* with statistical significance ($p<0.05$), demonstrating strong interdependence. This relationship not only reflects how expanded highway infrastructure directly boosts freight volume but also suggests that freight growth may conversely accelerate infrastructure development. While other indicators show statistical significance (>0.05), their marginal relevance should not diminish the value of infrastructure investment. Researchers must remain vigilant against potential biases and uncertainties arising from limited sample sizes.

The data on cargo turnover and total social logistics volume underwent Z-score standardization. Linear data from 2021 to 2023 were selected for temporal matching, and the Pearson correlation coefficient was employed to assess the linear correlation strength between transportation indicators and economic indicators. The results are presented in Table 7.

Table 7 Data on Cargo Turnover and Total Social Logistics Volume

		Z-score Freight Turnover	Z-score Total Social Logistics Volume
Z-score Freight Turnover	Pearson Correlation	1	0.999*
	Sig. (2-tailed)		0.020
	N	3	3
Z-score Total Social Logistics Volume	Pearson Correlation	0.999*	1
	Sig. (2-tailed)	0.020	
	N	3	3

It can be seen from the above table that the correlation coefficient between freight turnover and total social logistics volume is 0.999* ($p<0.05$), showing a significant positive correlation, indicating that the growth of freight turnover has a significant driving effect on the growth of total social logistics volume; the Pearson correlation coefficient is 0.999* and the significance level is less than 0.05, which further verifies the significance of the correlation between the two. The correlation coefficient shows that there is limited room for improvement in logistics efficiency in the traffic corridors of Wuhan Urban Agglomeration, and the transportation industry still relies on the extensive development mode of "exchanging volume for amount", and economies of scale have not been fully realized. Therefore, efforts should be made to expand high-value-added industries. At that time, the relevant correlation coefficient may be more significant, but the accidental risk brought by the small sample size should be guarded against. Finally, it is necessary to promote the transformation of the logistics industry from extensive growth (simple scale expansion) to benign growth (driven by efficiency improvement), so as to realize the sustainable development of the logistics industry in the traffic corridors of Wuhan Urban Agglomeration, and then improve its service capacity.

4. Conclusions and Suggestions

Comprehensive analysis shows that the scale of infrastructure (highways, railways, rail transit, etc.) of the traffic corridors in Wuhan Urban Agglomeration is expanding year by year, laying a foundation for the improvement of service capacity. The transportation service has strong resilience. The passenger and freight volume and turnover rebounded in 2023, but the overall situation still needs to be optimized. The environmental impact is controllable, the noise is stable, and the vegetation is increasing, but the fluctuation of the sound environment quality needs attention. The economic benefits are significant, and the total social logistics volume is growing steadily, but the logistics industry has an extensive mode of "exchanging volume for amount", and efficiency and structural optimization are the key. Empirical results show that there is a significant positive correlation between highway mileage and freight volume, and between freight turnover and total social logistics volume, which confirms the direct promotion effect of infrastructure on transportation efficiency and economy. However, attention should be paid to the insignificant correlation of some indicators and the limitation of small samples.

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