Research on Evaluation and Optimization Strategy of Road Traffic Resilience

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Abstract. In recent years, urban road traffic is frequently affected by various abnormal events, which not only damage the traffic facilities, but also have an impact on the operation of social economy. Therefore, it has become an important research direction to explore the resilience of urban road traffic, identify its influencing factors, and analyze the advantages and disadvantages of urban traffic resilience. This paper takes Beijing and Shanghai as the research objects, uses analytic hierarchy process (AHP) to construct the urban road traffic resilience evaluation index system, obtains the index data from 2017 to 2021, and evaluates the urban road traffic resilience according to the index weights by using the grey relational degree model. The main research content is the evaluation of urban road traffic resilience, the exploration of influencing factors and the optimization strategy. The results show that road traffic resilience in Beijing and Shanghai is closely related to each index.

Keywords: urban road traffic; Traffic resilience evaluation; Hierarchical analysis; Grey relational analysis

1 INTRODUCTION

With the frequent occurrence of natural disasters, uncertainty and variability have become the new normal of urban transportation operation, and the transportation environment is deteriorating, which poses severe challenges to urban transportation operation. Therefore, the development of road traffic resilience is extremely important for urban construction. At present, there is a lack of systematic and accurate research methods on the weight setting of road traffic resilience evaluation indicators, and the discussion of deep-seated problems is still insufficient. This paper evaluates the resilience of urban road traffic by constructing an evaluation index system of urban road traffic resilience. According to the results of the evaluation, the problems faced by urban traffic development are analyzed.

In terms of domestic research on resilient traffic evaluation, Li et al. [1] Ma Shuhong et al. [2] combined resilient city theory and complex network theory to build a resilience assessment model for urban agglomeration comprehensive transportation network. Ma Lingyong et al. [3] applied the resilient city theory to conduct an in-depth analysis on the existing problems of Daqing's road traffic system in terms of resilience.

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In foreign countries, for the flexible traffic theory, Murray-Tuite[4] was the first person to specifically define resilience in the context of traffic systems and put forward a measure of resilience. Serulle et al. [5] defined transportation system resilience as the ability of a transportation system to withstand disruptive events and restore its pre-disruption service level within a specified time frame. Bhavathrathan et al.[6] regard the resilience of a transportation system as the maximum disturbance or disturbance that a transportation system can withstand before transiting from one state to another.

2 EVALUATION INDEX SYSTEM CONSTRUCTION AND WEIGHT DETERMINATION

This paper constructs an evaluation system from the resilience of road traffic assets, network resilience and transportation quality resilience. In terms of the selection of specific indicators, transportation is a secondary indicator of the urban system in the ' Beijing Resilience Urban Planning Outline Study ', and its three-level indicators include : ' road network density, green travel ratio, and ten thousand car mortality in centralized construction areas '. The road network density of urban built-up area affects the adaptability and recovery of traffic system to various disturbances by optimizing the road network structure. The road area ratio of urban built-up area affects the adaptability of urban traffic system to various disturbances by improving traffic distribution and supporting emergency response. The mortality rate of 10,000 vehicles reflects the current situation of road traffic safety, and its level affects the development of traffic resilience. The proportion of green travel affects traffic resilience by reducing congestion, reducing the incidence of accidents, and improving energy efficiency.

Based on the above, the evaluation index system of urban road traffic is established. In terms of index weight calculation, follow the principle of analytic hierarchy process, confirm the weight of each index, and construct a judgment matrix. The weights of the above indicators are summarized, as shown in Figure 1. The toughness index score in the table is the product of the criterion layer weight and the index layer weight.

Target Tier	Criterion layer weights	Indicator Layer weights	Stats	Toughness Metrics Score
Urban transport resilience level	Resilience of road transport assets (0.19762)	Total urban road mileage (0.16378)	+	0.03237
		Traffic accident loss allowance (0.29726)	-	0.05874
		Urban transportation fixed asset investment (0.53896)	+	0.10651
	Resilience of road transport network (0.49048)	Length of road per capita (0.14722)	+	0.07221
		Area of road owned per capita (0.23551)	+	0.11551
		Rate of road area in urban built-up areas (0.18754)	+	0.09198
		Road network density in urban built-up areas (0.39578)	+	0.19412
		Length of public transport lines (0.03395)	+	0.01665
	Road transport quality resilience (0.3119)	Total daily trips in central urban areas (0.22677)	+	0.07073
		Proportion of green trips (0.08878)	+	0.02769
		Public transport vehicles per 10,000 people (0.14313)	+	0.04464
		Average equivalent sound level of traffic ambient noise (0.05664)	-	0.01767
		10,000 vehicle fatality rate (0.48468)	-	0.15117

Fig. 1. Weight of each indicator

3 EVALUATION OF URBAN ROAD TRAFFIC RESILIENCE

3.1 Evaluation Method Model Establishment

Take Beijing and Shanghai as examples to obtain the above 13 index data. The data based on which the indicators are established in this paper come from Beijing Statistical Yearbook, Shanghai Statistical Yearbook, China City Statistical Database, Shanghai Comprehensive Traffic Annual Report, Beijing Traffic Development Annual Report and other statistical data, which are summarized as shown in Figure 2. The urban road traffic resilience of Beijing and Shanghai was evaluated by using the grey relational analysis model.

Road traffic data of Beijing from 2017-2021

Indicators	2017	2018	2019	2020	2021
Total urban road mileage (km)	6359	6203	6156	6147	6168
Traffic accident loss allowance (ten thousand yuan)	3145.5	3519.6	3528	4942.3	5291.9
Urban transportation fixed asset investment (ten thousand yuan)	2038338	2457218	2408804	2892972	3498026
Length of roads per capita (km / 10,000 people)	7.17	7.22	7.54	7.62	8.4
Per capita road area (m2)	7.44	7.57	7.68	7.67	7.72
Rate of road area in urban built-up areas (%)	10.96	10.57	10.52	11.11	10.56
Density of road network in urban built-up areas (km/km ^{2})	3.94	3.81	3.66	3.66	3.48
Public transport line length (km)	1637	16290	27632	28418	28580
Total daily trips in Central urban areas (10,000)	3893	3924	3957	3619	3530
Percentage of green trips (%)	72.1	73	74.1	73.1	74
Public transport vehicles per 10,000 people (PCU)	26.55	18.24	17.41	17.02	16.45
Average equivalent sound level for traffic ambient noise (decibels)	69.3	69.3	69.6	69	69
10,000 vehicle deaths (%)	2.23	2.13	1.98	1.47	1.62

Road traffic data of Shanghai from 2017 to 2021

Indicators	2017	2018	2019	2020	2021
Total urban road mileage (km)	5224	5317	5494	5536	5844
Traffic accident loss allowance (10,000 yuan)	11363	27487	15969	31495	75477
Fixed asset investment in urban transportation (10,000 yuan)	1418858	876445	1075072	1511068	1446083
Length of roads per capita (km / 10,000 people)	7.67	7.52	7.64	7.42	8.6
Per capita road area (square meters)	12.34	12.49	12.7	12.47	13.1
Rate of road area in urban built-up areas (%)	8.96	9.26	9.33	9.64	9.96
Density of road network in urban built-up areas (km/km ^{2})	4.3	4.44	4.47	4.71	4.82
Public transport line length (km)	24161	24525	24780	249323	25185
Total daily trips in Central urban areas (10,000)	3253	3268	5710	3274	5400
Percentage of green trips (%)	72.1	73	74.1	75	72.1
Public transport vehicles per 10,000 people (vehicles)	13.94	14.53	15.37	16.33	17.09
Average equivalent sound level of traffic ambient noise (decibels)	69.8	69.3	68.3	68.2	68.4
Death rate per 10,000 vehicles (%)	1.7	2.14	2.13	2.19	1.61

Fig. 2. Urban road traffic data

Optimal Index Set Selection. In the evaluation index system, 10 indicators are positive indicators and 3 indicators are negative indicators. After dimensionless data processing, the maximum principle is selected for positive indicators and the minimum principle for negative indicators, and the optimal value of each indicator is selected from the road traffic data of Beijing and Shanghai from 2017 to 2021 as the optimal index set.

Calculation of Grey Correlation Coefficient. Through the correlation coefficient calculation formula, the correlation coefficient matrix of the two cities is calculated. In this paper, the resolution coefficient is 0.5, and the correlation coefficient calculation formula is as follows. The calculation results are shown in Figure 3.

$$r_{ij} = \frac{min_i\left(min_j\left|s_{0j}-s_{ij}\right|\right)+\rho\, max_i\left(max_j\left|s_{0j}-s_{ij}\right|\right)}{\left|s_{0j}-s_{ij}\right|+\rho\, max_i\left(max_j\left|s_{0j}-s_{ij}\right|\right)} \tag{1}$$

$$R_{Beijing} = \begin{bmatrix} 1.0000 & 0.9161 & 0.8935 & 0.8893 & 0.8991 \\ 1.0000 & 0.7415 & 0.7372 & 0.3739 & 0.3333 \\ 0.3437 & 0.4235 & 0.4124 & 0.5582 & 1.0000 \\ 0.6318 & 0.6414 & 0.7105 & 0.7301 & 1.0000 \\ 0.8816 & 0.9329 & 0.9812 & 0.9766 & 1.0000 \\ 0.9516 & 0.8453 & 0.8334 & 1.0000 & 0.8429 \\ 1.0000 & 0.8873 & 0.7853 & 0.7853 & 0.6900 \\ 0.3520 & 0.3508 & 0.8751 & 0.9762 & 1.0000 \\ 0.9421 & 0.9693 & 1.0000 & 0.7550 & 0.7093 \\ 0.9093 & 0.9480 & 1.0000 & 0.9525 & 0.9950 \\ 1.0000 & 0.4011 & 0.3784 & 0.3686 & 0.3552 \\ 0.9844 & 0.9844 & 0.9692 & 1.0000 & 1.0000 \\ 0.3950 & 0.4292 & 0.4932 & 1.0000 & 0.7679 \end{bmatrix} \quad R_{Shanghai} = \begin{bmatrix} 0.9100 & 0.9225 & 0.9471 & 0.9532 & 1.0000 \\ 1.0000 & 0.6693 & 0.8763 & 0.6185 & 0.3373 \\ 0.9413 & 0.6995 & 0.7721 & 1.0000 & 0.9579 \\ 0.9058 & 0.8923 & 0.9031 & 0.8834 & 1.0000 \\ 0.9497 & 0.9593 & 0.9729 & 0.9580 & 1.0000 \\ 0.9150 & 0.9389 & 0.9447 & 0.9711 & 1.0000 \\ 0.9090 & 0.9318 & 0.9369 & 0.9793 & 1.0000 \\ 0.3333 & 0.3337 & 0.3339 & 1.0000 & 0.3343 \\ 0.6712 & 0.6726 & 1.0000 & 0.6731 & 0.9418 \\ 0.9663 & 0.9765 & 0.9893 & 1.0000 & 0.9663 \\ 0.8495 & 0.8742 & 0.9118 & 0.9590 & 1.0000 \\ 0.9798 & 0.9860 & 0.9987 & 1.0000 & 0.9974 \\ 0.9597 & 0.8019 & 0.8049 & 0.7872 & 1.0000 \end{bmatrix}$$

Fig. 3. Correlation coefficient matrix

Determine the Weight Matrix W of Each Evaluation Index. The index weights calculated according to analytic hierarchy process are as follows:

$$W = \begin{bmatrix} 0.0324 \\ 0.0587 \\ 0.1065 \\ 0.0722 \\ 0.1155 \\ 0.0920 \\ 0.1941 \\ 0.0167 \\ 0.0707 \\ 0.0277 \\ 0.0446 \\ 0.0177 \\ 0.1512 \end{bmatrix}^T$$

Calculate the Grey Linkage Matrix. The correlation coefficient between each evaluation object and the optimal index is composed of the evaluation matrix, and the gray correlation matrix is calculated. According to the analytic hierarchy process, the weight matrix of each evaluation index is calculated, and the correlation between each evaluation object and the optimal index is analyzed.

$$W = [w_1,\ w_2,\ w_3,\ \cdots w_n] \tag{2}$$

$$A = W * R \tag{3}$$

the gray connection degree is calculated as follows.

$$a_i = \sum_{i=1}^{n} w_i\, r_{ij},\ (i = 1,\ 2,\ \cdots,\ n) \tag{4}$$

Year grey correlation degree matrix of urban road traffic resilience in Beijing:

$$A_{Beijing} = [0.7763 \quad 0.7232 \quad 0.7314 \quad 0.8015 \quad 0.7984]$$

Year grey correlation matrix of urban road traffic resilience in Shanghai:

$$A_{Shanghai} = [0.9043 \quad 0.8440 \quad 0.8944 \quad 0.8990 \quad 0.9404]$$

3.2 Analysis of Evaluation Results

According to the calculation of the above grey correlation degree matrix, the road traffic resilience correlation degree as shown in Figure 4 is obtained. The correlation degree of resilience of urban road traffic in Beijing tends to be between 0.7232 and 0.8015, and that of Shanghai tends to be between 0.8440 and 0.9404. It can be seen that the correlation degree of resilience of urban road traffic in the two cities is the lowest in 2018, and the correlation degree of resilience of urban road traffic in Beijing is the highest in 2020. The correlation of resilience of urban road traffic in Shanghai will be the highest in 2021.

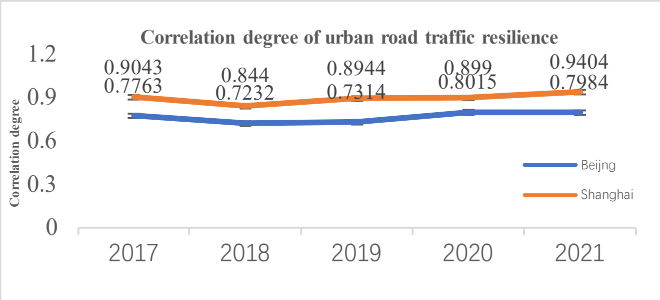

Fig. 4. Road traffic resilience correlation

From the above, the road traffic resilience of the two cities showed a stable trend of first decreasing and then rising, with a small change amplitude and tending to be flat. According to the above correlation coefficient matrix, the correlation degree between urban road traffic resilience and various indicators is mostly above 0.5, which belongs to a high correlation level, indicating that there is a close correlation between urban road traffic resilience and various indicators. In the resilience index scores, the network density and per capita road area of urban built-up areas have higher scores, while the length of public transport lines and the proportion of green trips have lower scores.

3.3 Strategies for Improving Resilience of Urban Road Traffic

The following road traffic resilience improvement strategies are proposed : in terms of urban road network density and network layout, increase road expansion and new construction, broaden existing roads, add traffic nodes, and build new road networks ; in terms of increasing the proportion of green travel, we should strengthen the priority of public transport : increase financial investment, expand the coverage and operation frequency of public transport networks such as buses and trams, so as to alleviate the pressure of passenger flow.

For cities with different socio-economic conditions, hierarchical assessments can be conducted from road asset resilience, network resilience and transport quality resilience, so as to identify the weak links in traffic resilience of each city and formulate corresponding optimization measures accordingly. Secondly, considering the economic situation of the city, rationally allocate resources and funds, and apply them to the specific environment of different cities by studying the construction cases of other cities and learning experience.

4 CONCLUSIONS

This paper takes Beijing and Shanghai as the research objects, constructs the evaluation index system of urban road traffic resilience, and evaluates the urban road traffic resilience. The conclusions are as follows : From the perspective of the region as a whole, the road traffic resilience of Beijing and Shanghai shows a trend of slowly decreasing first and then rising, and tends to be gentle. The correlation between urban road traffic resilience and each index is mostly above 0.5, which belongs to a high correlation level. Urban road traffic resilience is closely related to each index. The resilience index scores of road network density, vehicle mortality rate and per capita road area in urban built-up areas are higher. The resilience index scores of public transport line length and green travel ratio are low, and it is still necessary to improve the quality resilience of road traffic transportation and the quality resilience level of road traffic transportation.

For extremely destructive events, this paper considers indicators related to disaster response, such as the death rate of ten thousand vehicles, reflecting the safety and response capacity of the transportation system in the face of traffic accidents. Through the grey correlation model, the urban road traffic resilience is evaluated, and the data of different years are analyzed, so as to observe the performance and recovery ability of the traffic system in different situations. This paper mainly focuses on Beijing and Shanghai, but by comparing the resilience performance of different cities and drawing on the experience of other cities in dealing with extreme events, it identifies the differences and similarities in road traffic resilience between different cities. This helps to understand the impact of different urban structures, population density, economic development level and traffic management models on traffic resilience.

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