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Evaluation of Transfer Efficiency Between Urban Rail Transit and Conventional Bus

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Abstract. Aiming at the problem of transfer between urban rail transit and conventional bus, we select four first level indicators such as efficiency, convenience, comfort and synergy as well as ten second level indicators. Firstly, expert scoring method is used to calculate the indicator weight, then the analytic hierarchy process is used to establish an evaluation model, and a comprehensive evaluation is conducted to obtain the evaluation grade. Finally, taking the transfer between Dayang station of Jinan Rail Line 1 and the surrounding public transport as an example, the paper analyzes the main reasons that affect the transfer efficiency and gives targeted suggestions, so as to improve the overall service quality of the urban public transport system and provide certain decision-making support for public transport operators.

Keywords: Urban rail transit · conventional bus · analytic hierarchy process · transfer efficiency evaluation

1 Introduction

With the continuous acceleration of China's urbanization process and the rapid development of the economy, urban residents travel more and more frequently, resulting in a sharp contradiction between transportation demand and supply, and urban public transportation can effectively solve this problem. Urban rail transit has the characteristics of resource saving, comfort and safety, large traffic volume, fast speed, etc. It plays a backbone role in the urban public transport system, and conventional bus transit is flexible in short distance transportation. The reasonable connection and effective transfer between urban rail transit and conventional bus transit are of great significance for solving the problem of urban traffic congestion and improving the convenience and comfort of passengers.

The development of urban rail transit in foreign countries is earlier, and many achievements have been made in the transfer between urban rail transit and conventional public transport [1–3]. Lee [4] studied the transfer conditions between subway and bus in Germany, and established an evaluation model for the coordination of rail transit and conventional bus transfer. Robinson et al. [5] analyzed how to improve the transfer efficiency of rail transit and established a generalized transfer efficiency calculation model

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between rail transits. Pelletier et al. [6] established an evaluation model based on passenger service according to the passenger flow data of conventional public transit, and evaluated the transfer efficiency according to the data.

With the continuous development of urban rail transit in China, many domestic experts and scholars have also done a more in-depth study on the transfer between urban rail transit and conventional bus. Based on the analysis of the influencing factors of the connection and transfer between urban rail transit and conventional bus transit, the transfer evaluation index system is constructed by Tang [7], and the comprehensive evaluation model of transfer is established by using entropy method and TOPSIS (Technique for Order Preference by Similarity to an Ideal Solution) evaluation method. Through case analysis of the transfer between rail transit and conventional bus in Nanning, the rationality and applicability of Entropy-TOPSIS model in the comprehensive evaluation of transfer are studied. Based on the passenger flow survey of the urban commercial area, Ma et al. [8] summarized the traffic characteristics of the rail transit and conventional public transit in the commercial area. They also established the coordination degree evaluation model between rail transit and conventional public transit transfer. Zhong et al. [9] took the transfer between rail transit and bus in Chongqing as an example, carried out field investigation to analyse the transfer paths, and provided improvement measures for the development and planning of rail transit in Chongqing. Li et al. [10] discussed residents' travel information cognition, transfer information cognition and satisfaction research based on the structural equation model. Sun et al. [11] established a transfer model between rail transit and conventional bus at the intersections based on the transfer rules. Based on the analytic hierarchy model, this paper evaluates the transfer efficiency of urban rail transit and conventional bus, and takes the Dayang station of Jinan Metro as an example to analyze the existing problems and propose improvement measures and methods.

2 Construction of Transfer Efficiency Evaluation Model

2.1 Selection of Evaluation Indicators

Based on the analysis steps of AHP method, the three-stage structure model of "target layer → rule layer → index layer" is used to select the practical and effective evaluation indicators. The evaluation index system constructed in this paper is shown in Table 1.

2.2 Quantification of Evaluation Indicators

Through comprehensive analysis, the indicators are divided into five grades: Grade A stands for excellent, Grade B stands for good, Grade C stands for average, Grade D stands for not very satisfied, and Grade E stands for bad.

(1) Average transfer time.

The average transfer time shall be determined by averaging the time consumed by each transfer passenger. According to existing researches [9–11], less than 10 min, 10–15 min, 15–20 min and 20–30 min are selected as reference standards to calculate the average transfer time. Average transfer time evaluation grade is shown in Table 2.

Table 1. Evaluation index system

Target layer	Rule layer	Index layer
Evaluation index system for transfer efficiency of urban rail transit and bus	Efficiency	Average transfer time (U_1)
		Average transfer distance (U_2)
		Transport capacity matching degree (U_3)
	Convenience	Timeliness of transfer information (U_4)
		Number of bus lines transferred (U_5)
	Comfort	Per capita transfer area (U_6)
		Per capita transfer satisfaction (U_7)
	Synergy	Transfer guidance facilities (U_8)
		Number of transfer intersections (U_9)
		Station layout planning (U_{10})

Table 2. Average transfer time evaluation grade

Evaluation grade	A	B	C	D	E
Time	[0,5]	(5,10]	(10,15]	(15,20]	(20,30]
Score	[90,100]	[80,90)	[70,80)	[60,70)	[0,60)
Description	Short	Acceptable	A little long	Long	Too long

(2) Average transfer distance.

The smaller the average transfer distance, the more convenient the station is. The calculation formula of average transfer distance P is:

$$P = \sum_{i=1}^{n} \omega_i L_i \tag{1}$$

ω_i is the number of regular bus stations connecting the transfer station of urban rail transit, L_i is the number of regular buses that connected with urban rail transit transfer station i, and n is the number of transfer stations. Evaluation grade of average transfer distance is shown in Table 3.

(3) Transport capacity matching degree.

The data of passenger flow during peak hours are selected to calculate the matching degree of urban rail transit and conventional bus transit.

The transportation capacity C_r of urban rail transit is:

$$C_r = \frac{nTB_rJ_r(\eta_{rl} - \eta_{rt})}{I_r} \tag{2}$$

Table 3. Evaluation grade of average transfer distance

Evaluation grade	A	B	C	D	E
Distance	[0,200]	(200,300]	(300,400]	(400,500]	(500,1000]
Score	[90,100]	[80,90)	[70,80)	[60,70)	[0,60)
Description	Short	Acceptable	A little long	Long	Too long

The transportation capacity C_b of bus is:

$$C_b = \sum_{l=1}^{N_2} \frac{TB_b J_b \eta_b}{I_b} \tag{3}$$

The matching degree of transport capacity H is:

$$H = \frac{C_b}{C_r} \tag{4}$$

T refers to the peak period, I_r refers to the departure interval of urban rail transit during the peak period, I_b refers to the departure interval of conventional bus during the peak period, B_r refers to the average boarding and alighting passenger flow of each train at the rail transit station during the peak period, and B_b refers to the average boarding and alighting passenger flow of each bus during the peak period. η_{rl}, η_{rt} refers to the number of bus departure routes and routes through rail transit stations, η_b refers to the number of bus routes, J_r refers to the load factor of urban rail transit, J_b refers to the load factor of bus, l refers to the departure route of bus, and N_2 refers to the total number of departure routes of regular bus. The corresponding evaluation grades are shown in Table 4.

(4) Per capita transfer area.

Per capita transfer area refers to the platform area that can be used by each transfer passenger during peak hours. That is, the transfer area owned by each passenger. The calculation formula is:

$$Z = \frac{60S\beta}{Q_N T} \tag{5}$$

Table 4. Evaluation grade of transport capacity matching degree

Evaluation grade	A	B	C	D	E
Degree	[0.8,1.0]	[0.7,0.8)	[0.6,0.7)	[0.4,0.6)	[0,0.4)
Score	[90,100]	[80,90)	[70,80)	[60,70)	[0,60)
Description	Consistent	Basically consistent	Surplus	A large surplus	Far exceeds

Table 5. Evaluation grade of per capita transfer area

Evaluation grade	A	B	C	D	E
Area	[2.33,3.26]	[1.40,2.33)	[0.93,1.40)	[0.47,0.93)	[0,0.47)
Score	[90,100]	[80,90)	[70,80)	[60,70)	[0,60)
Description	Very spacious	Spacious	A little crowded	Crowded	Very crowded

In the formula, S refers to the area of transfer infrastructure (m^2), mainly including the waiting area of passengers in urban rail transit stations and the platform area of transfer bus stations. β refers to the proportion of transfer passenger flow, Q_N refers to the passenger flow of boarding and alighting, and T refers to the average transfer time.

The evaluation grade of per capita transfer area is shown in Table 5.

(5) Timeliness of transfer information.

Timeliness of transfer information refers to the indicators that provide various information at bus stations and subway stations. High accuracy of information between urban rail transit and bus will make passengers transfer more convenient.

(6) Number of bus lines transferred.

This indicator is selected for the reason that the transfer capacity is not only affected by subway stations, but also the number of bus operation lines.

(7) Per capita transfer satisfaction.

Per capita transfer satisfaction refers to the average value of the transfer satisfaction score obtained during the survey. The transfer efficiency of the transfer station is evaluated according to the grade calculated by this indicator.

(8) Transfer guidance facilities.

Transfer guidance facilities also include in-station guidance facilities. Guidance facilities and transfer signs are important factors affecting transfer efficiency.

(9) Number of transfer intersections.

Most of the transfers are outside the station, which requires passengers to get on the ground first. This will waste passengers transfer time, so the number of transfer intersections should also be considered when selecting indicators.

(10) Station layout planning.

Station layout planning plays an important role in promoting the development of the city in the future. Unreasonable station planning will bring great inconvenience to the surrounding residents, so the station layout planning is also one of the reasons that affect the transfer efficiency.

All the qualitative evaluation index grade are shown in Table 6.

2.3 Determination of Evaluation Index Weight

The AHP judgment scale used in calculating the index weight is shown in Table 7.

Table 6. Qualitative evaluation index grade

Grade	A	B	C	D	E
Score	[90,100]	[80,90)	[70,80)	[60,70)	[0,60)
U_4	Very timely	Timely	Basically satisfied	Update slowly	Serious procrastination
U_5	Huge	Quite a lot	Enough	Rarely	Serious deficiency
U_7	Very satisfactory	Satisfactory	Basically satisfied	Dissatisfied	Extremely dissatisfied
U_8	Very reasonable	Reasonable	Acceptable	Unreasonable	Very unreasonable
U_9	Very reasonable	Reasonable	Acceptable	Unreasonable	Very unreasonable
U_{10}	Very reasonable	Reasonable	Acceptable	Unreasonable	Very unreasonable

Table 7. AHP judgment scale

Scale	definition	explain
1	Equally important	Indicates that the two elements are equally important
3	Slightly important	The former element is slightly more important than the latter
5	Strongly important	The former element is more important than the latter
7	Very strongly important	The former element is more important than the latter
9	Absolutely important	The former element is absolutely more important than the latter
2,4,6,8	Intermediate value of the above two judgment levels	It indicates that the discount value between the above standards
Reciprocal	Contrast	The order of comparison is switched

Construct the following original judgment matrix:

$$\overline{A} = \{\overline{a}_{ij}\}_{\max} = \begin{bmatrix} \overline{a}_{11} & \overline{a}_{12} & \cdots & \overline{a}_{1n} \\ \overline{a}_{21} & \overline{a}_{22} & \cdots & \overline{a}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \overline{a}_{n1} & \overline{a}_{n2} & \cdots & \overline{a}_{nn} \end{bmatrix} \tag{6}$$

The above judgment is tested for calculation consistency indicators:

$$CI=\frac{\lambda_{\max}-n}{n-1} \tag{7}$$

The consistency index CI is obtained by averaging RI. When the random consistency ratio $CR = \frac{CI}{RI} < 0.10$, it means that the results of AHP have satisfactory consistency, that is, the distribution of weight coefficients is reasonable. According to the relative importance of each index scored by experts, a judgment matrix is established, and then AHP method is used to calculate the weight of each index and to test the consistency to determine the rationality of the index.

The final evaluation index weight calculation results are shown in Table 8:

Final evaluation grade is the sum of the product of the weight of each index weight and grade evaluation. The calculation formula is as following.

$$U = \sum_{i=1}^{n} U_i \eta_i \tag{8}$$

U is the final evaluation grade, U_i is the average score of experts for each indicator, η_i is the weight of each indicator.

Table 9 shows the classification of transfer efficiency evaluation grades of urban rail transit and conventional bus.

Table 8. Index weight calculation results

Evaluating indicator	Judgement matrix	Weight	Consistency check
Efficiency	$\begin{pmatrix} 1 & 3 & 3 & 2 \\ 1/3 & 1 & 2 & 1 \\ 1/3 & 1/2 & 1 & 2 \\ 1/2 & 1/1 & 1/2 & 1 \end{pmatrix}$	0.4649	$CR < 0.1$ Pass consistency check
Convenience		0.2041	
Comfort		0.1715	
Synergy		0.1595	
U_1	$\begin{pmatrix} 1 & 3 & 2 \\ 1/3 & 1 & 1/2 \\ 1/2 & 1/3 & 1 \end{pmatrix}$	0.1047	$CR < 0.1$ Pass consistency check
U_2		0.2583	
U_3		0.6369	
U_4	$\begin{pmatrix} 1 & 3 \\ 1/3 & 1 \end{pmatrix}$	0.75	$CR < 0.1$ Pass consistency check
U_5		0.25	
U_6	$\begin{pmatrix} 1 & 2 \\ 1/2 & 1 \end{pmatrix}$	0.6667	$CR < 0.1$ Pass consistency check
U_7		0.3333	
U_8	$\begin{pmatrix} 1 & 3 & 2 \\ 1/3 & 1 & 1/2 \\ 1/2 & 1/3 & 1 \end{pmatrix}$	0.1958	$CR < 0.1$ Pass consistency check
U_9		0.3108	
U_{10}		0.4934	

Table 9. Evaluation grade classification

Evaluation grade	A	B	C	D	E
Score	[90,100]	[80,90)	[70,80)	[60,70)	[0,60)
Description	Very good	Good	Not so good	Worse	Worst

3 Case Analysis

3.1 Basic Information of Dayang Rail Transit and Conventional Bus Transfer Hub

Jinan Metro Line 1 is located in the west of Jinan, which runs from north to south. The starting and ending stations are Gongyanyuan station and Fangte station, with a total mileage of 26.27km. More than 30 bus lines are covered around this line.

Dayang Station is located at the intersection of Qilu Avenue and Jingshi West Road, adjacent to Jingshi Road. Dayang station is surrounded by eight bus lines: No.7, No.20, No.56, No.61, No.78, No.126, No.141 and T15.

3.2 Analysis on Transfer Efficiency of Dayang Station

Ten experts were invited to score the evaluation indicators, and the passenger flow survey data were used to obtain quantitative indicator data of Dayang station. The results of passenger questionnaire are submitted to experts for comprehensive scoring to obtain the most reasonable data.

(1) Capacity matching degree:

$$H = \frac{C_b}{C_r} = \frac{890}{1750} = 0.51 \tag{9}$$

It can be seen from Table 2.4 that the matching degree of transportation capacity is the most scientific and reasonable when it is between 0.8–1.0. In the actual calculation example, the matching degree of transportation capacity is 0.51, and the grade is D, which is poor.

(2) Per capita transfer area:

$$Z = \frac{60S\beta}{Q_N T} = \frac{60 \times 680 \times 2.2}{2460 \times 30} = 1.22\left(m^2\right) \tag{10}$$

According to the calculation, the per capita transfer area of Dayang station is 1.22m2, and the evaluation grade of transfer area is grade C. The transfer passenger flow density is large, but within the acceptable range.

(3) Average transfer distance:

$$P = \sum_{i=1}^{n} \omega_i L_i = 223(m) \tag{11}$$

Table 10. Weight Summary of transfer efficiency indicators

Index	$U1$	$U2$	$U3$	$U4$	$U5$	$U6$	$U7$	$U8$	$U9$	$U10$
$U1$	1	2	1/3	2	3	1	3	3	3	2
$U2$	1/2	1	1/3	2	3	2	3	3	2	2
$U3$	3	3	1	4	3	3	3	3	4	3
$U4$	1/2	1/4	1/4	1	2	1/3	1	1/2	3	2
$U5$	1/3	1/3	1/3	1/2	1	1/3	1/2	2	2	2
$U6$	1	1/2	1/3	3	3	1	3	2	3	2
$U7$	1/3	1/3	1/3	1	2	1/3	1	2	2	1
$U8$	1/3	1/3	1/3	2	1/2	1/2	1/2	1	2	2
$U9$	1/3	1/2	1/4	1/3	1/2	1/3	1/2	1/2	1	2
$U10$	1/2	1/2	1/3	1/3	1/2	1/2	1	1/2	1/2	1
Weight	0.1468	0.1316	0.2442	0.0697	0.0592	0.1278	0.0681	0.0617	0.0436	0.0473

It can be seen from Table 2.3 that the average transfer distance between Dayang station and surrounding bus stations is 223m, which belongs to Class B. The corresponding level describes that the transfer distance is small and the transfer convenience is high.

According to the questionnaire, the average transfer time is 10–15 min, and the evaluation grade is C. The waiting time for passengers to transfer is relatively reasonable.

According to Table 2.8, different indicators have different importance for the evaluation system. After careful analysis, experts need to compare the ten indicators in pairs to get the final calculation results as shown in Table 10.

According to the total efficiency calculation formula, the corresponding grade of each indicator is comprehensively scored, and the results are shown in Table 11.

According to the above data, the score of Dayang station transfer efficiency is 83.9, and the comprehensive evaluation grade is B.

3.3 Comprehensive Evaluation of Station Transfer Efficiency

According to the calculation results, the key indicators in the criterion layer are efficiency (0.4649) and convenience (0.2041). Among the ten indicators in the indicator layer, the most prominent one is the matching degree of transport capacity (0.2442), the average transfer time (0.1468), the average transfer distance (0.1316), and the average transfer area (0.1278). This shows that the transfer efficiency will be affected due to the transfer time, transfer distance, and transfer area when urban rail transit transfers with conventional bus. This is also an urgent problem to be solved in the integrated development of urban rail transit and conventional public transport.

On the premise that the urban rail transit lines are fixed and the transportation capacity meets the design requirements, in order to improve the transfer efficiency between them, it is necessary to adjust the location of stations, optimize the waiting area of public transport, reasonably plan the distribution of passenger flow, shorten the departure

Table 11. Transfer efficiency evaluation of Dayang station

Evaluating indicator	Weight	Grade	Corresponding score
Average transfer time	0.1468	C	77.6
Average transfer distance	0.1316	B	75.9
Capacity matching degree	0.2442	D	65.5
Timeliness of transfer information	0.0697	A	93
Number of bus lines transferred	0.0592	A	90.6
Per capita transfer area	0.1278	B	86.7
Per capita transfer satisfaction	0.0681	B	89.3
Transfer guidance facilities	0.0617	A	92.2
Number of transfer intersections	0.0436	B	81.6
Station layout planning	0.0473	C	79.6
Transfer efficiency evaluation of Dayang station	B	83.9	

interval in peak hours or increase the number of trains in peak hours, so as to reduce the transfer time and distance of passengers and improve the overall transfer efficiency.

4 Conclusion

Considering the efficiency, convenience, comfort and synergy, this paper analyzes the transfer efficiency between Dayang station of Jinan Rail Line 1 and the surrounding conventional bus lines in order to improve the transfer organization of urban rail transit and other public transportation method. From the perspective of meeting the transfer needs of passengers, in order to improve the convenience and comfort of the transfer between urban rail transit and conventional transport, and in combination with the current development status of urban rail transit and conventional public transport, The calculated transfer efficiency score of Dayang station is 83.9, and the comprehensive evaluation grade is B. Corresponding improvement measures are proposed to improve the overall transfer efficiency. The research in this paper can provide some guidance for the construction of comprehensive transportation hub.

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