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EVALUATION OF URBAN PASSENGER TRANSPORT STRUCTURE

Sheng-rui ZHANG
Associate Professor
School of Highway
Chang'an University
Xi'an
710064 China
Fax: +86-29-82334256
E-mail: zhangsr@chd.edu.cn

Wei ZHOU
Professor
China Academy of Transportation Science
Beijing
100029 China
Fax: +86-10-64914815
E-mail: Zhw59@hotmail.com

Chunfu SHAO
Professor
Beijing Jiaotong University,
Beijing
100044 China
Fax: +86-10-51688344
E-mail: cfshao@center.njtu.edu.cn

Abstract: Base on the system analysis principle and the characteristics of urban passenger transport structure, this paper sets up the comprehensive evaluation indicator system from three aspects: the traffic function, economic benefit and environment benefit, discusses the method of quantity-turning of evaluation indicator in different traffic modes; according to the biggest utility theory and the correlation degree theory of grey system, puts forward the conception of correlation degree of the existed urban passenger transport structure relative to local-optimization structure, and works out the weights of indicators by AHP method, then sets up the model of comprehensive evaluation of urban passenger transport structure. Finally, the method has been applied in evaluating the passenger transport structure of Xi'an of China, and the result indicates that the evaluation method is easy to put in practice and in accord with the practical condition.

Key words: passenger transport structure, indicator system, evaluation, correlation degree

Passenger transport structure of urban traffic is the composition of the proportion that all kinds of traffic modes share in total trip in the urban traffic system. That is the proportion of all kinds of vehicles which people choose to travel. In the urban traffic system, all kinds of traffic modes, which are used as direct carries and tools to finish the traffic demand, have important influences on operation efficiency of urban traffic, but there are great differences for different vehicles in some indicators, such as operation pattern, operating speed, carrying capacity, transportation cost and accessibility. Therefore, whether reasonable or not for evaluating the passenger transport structure of a city has a great significance for analyzing urban traffic efficiency and solving urban traffic problems.

At present, people often evaluate urban passenger transport structure with qualitative method, but this kind of method has a very great subjectivity. So it is essential to look for a kind of scientific, reasonable and quantitative evaluation method of the passenger transport structure. According to the characteristics of different traffic modes, this paper sets up the evaluation indicator system of urban passenger transport structure, calculates the correlation degree of the existed urban passenger transport structure relative to optimization structure, and then uses AHP method to carry out comprehensive evaluation.

1. EVALUATION INDICATOR SYSTEM AND QUANTITATIVE ATTRIBUTE VALUE

1.1 Evaluation Indicator System

Urban passenger transport structure is a complicated system, and systematic complexity results in the variety of evaluation indicator. Meanwhile, there are some influences and restrictions among these indicators. So setting up a set of evaluation indicator system with clear level and reasonable relation is the prerequisite guaranteeing the success of system evaluation. According to the system analysis theory, this paper selects respectively the evaluation indicators from three subsystems: traffic function, economic benefit and environment benefit, taking comprehensiveness, conciseness, maneuverability and comparability as the principle, and evaluates the reasonability of the urban passenger transport structure. The evaluation indicator system is shown in Figure 1.

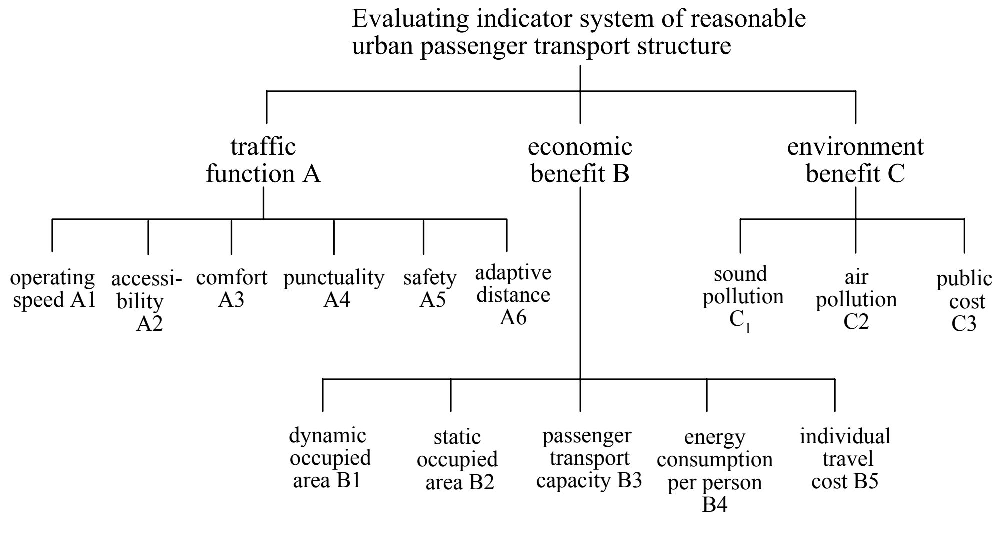

Figure 1. Reasonable Evaluation Indicator System of Urban Passenger Transport Structure

1.2 Quantity-turning of the Characteristic Indicators of Different Traffic Modes

Every kind of traffic mode has its specific social background and economic background when it came into being. Different traffic modes have different adaptive range, and there are different advantages within the range of a certain distance or under traffic demand. Now the characteristic indicators of different traffic modes are generalized in Table 1.

Table 1. Characteristic Indicator of Main Traffic Modes

Characteristic indicators		walk	bicycle	motor -cycle	private car	taxi	bus	light rail	sub-way
Traffic function (A)	adaptive distance/km	0~ 1.5	0.5 ~6.0	1~ 12	>2	1.5~ 13.0	2.0~ 10.0	3.0~ 20.0	4.0~ 30.0
	Speed /km·h^{-1}	3~5	11~14	15~40	25~50	20~50	16~25	20~35	30~40
	accessibility	E	E	E	G	M	B	W	W
	comfort	G	M	M	E	E	G	E	E
	safety	M	B	W	B	B	G	E	E
	punctuality	E	E	E	E	E	G	E	E
Economic benefit (B)	dynamic occupied area(m^2/seat)	0.8~ 1.2	5.0~ 8.0	8.0~ 15.0	15.0~ 25.0	10.0~ 20.0	1.0~ 2.0	0.5	
	static occupied area (m^2/seat)	0.3	0.8	1.2~ 1.5	5.0~ 6.0	4.0~ 5.0	0.5~ 0.7	0.5	0.6
	passenger transport capacity /person·km·h^{-1}	5	20	50	70	80	800	5000	10000
	user's expense(yuan)	0	0.3	4	18	10	1.5	3.0~ 4.0	3.0~ 5.0
	energy consumption /10^{9}J·(km·person)$^{-1}$	0.16	0.06	0.5	1	0.8	0.17	0.1	0.08
Environmental benefit (C)	sound pollution (It is one with the bus)	0.01	0.1	10	20	16	1	0.5	
	air pollution (It is one with the bus)	0.001	0.01	12	14	10	1		
	public cost	E	E	W	B	B	M	G	G

(E~ excellent; M~ moderate; B~ bad; W~ worst; G~ good ;)

The indicators in Table 1 have no-commensurability because of the difference of their own unit and magnitude, so they are difficult to compare. Therefore, in order to reflect the actual conditions as much as possible, we should exclude the influence caused by different units and the great difference among indicators' magnitude of them, and need to deal with the indicators non-dimensionally before we evaluate the passenger transport structure. At first, we will divide the evaluated results into a certain grade for the qualitative indicators, such as "excellent", "good", "moderate", "bad", "worst", and then make these evaluated grades form the evaluation domain. According to the results of expert investigation, we adopt statistical analysis method to ascertain interval value of evaluation standard of every indicator, and it is shown in Table 2.

Table 2. Evaluation Standard of Indicator

Evaluation grade	excellent	good	moderate	bad	worst
Value standard	1.0～0.80	0.80～0.60	0.60～0.40	0.40～0.20	0.20～0

For the quantitative indicators, according to the reference, this paper adopts the following two kinds of non-dimensional standard functions and deals with them, in which m_i and M_i represent the minimum and the maximum of evaluation indicator U_i respectively.

1) The lower the quantitative indicators, the more excellent the non-dimensional standard function

$$r_i = u(x_i) = \begin{cases} 1 & (x_i \le m_i) \\ \dfrac{M_i - x_i}{M_i - m_i} & (m_i < x_i < M_i) \\ 0 & (x_i \ge M_i) \end{cases}$$

2) The higher the quantitative indicators, the more excellent the non-dimensional standard function

$$r_i = u(x_i) = \begin{cases} 1 & (x_i \ge M_i) \\ \dfrac{x_i - m_i}{M_i - m_i} & (m_i < x_i < M_i) \\ 0 & (x_i \le m_i) \end{cases}$$

Using the above-introduced principal of non-dimensional qualitative indicators and non-dimensional quantitative indicators, according to the evaluation grade of qualitative indicators, this paper, at first, transforms the qualitative evaluation into the corresponding interval of evaluation, and then chooses the evaluation intermediate value referring to Table 2 generally. The quantitative indicators, not having been quantitative, are calculated respectively by two kinds of different standard functions according to indicators character. When an evaluation indicator lies in an interval, the non-dimensional value is corresponding to an interval value. Non-dimensional values of different indicators are shown in Table 3.

2. REALIZATION ON COMPREHENSIVE EVALUATION

2.1 The Ascertaining of the Proportion of Different Traffic Modes when the Sub-objective Comes to the Optimum

The reasonable urban passenger transport structure means the suitable proportion of trip in the whole urban traffic system which all kinds of traffic modes share; every traffic mode gives the greatest advantage in its scope of application. Under the fulfillment of the demand of urban land planning, it doesn't bring so much total traffic amount that cause traffic jam, and make good economic benefit and environment benefit while meeting urban traffic demand. Because different traffic modes have different trip characters, when the sub-objectives: traffic function, economic benefit and environment benefit make the most utility respectively, we can use the following model to ascertain the proportion of all kinds of traffic modes respectively.

Table 3. Non-dimensional Values of Different Traffic Modes Characteristic Indicators

Goal	characteristic indicators	walk	bicycle	motor-cycle	private car	taxi	bus	light rail	sub-way
Traffic function	adaptive distance	0~0.05	0.02~0.20	0.03~0.40	1.000	0.05~0.43	0.07~0.33	0.1~0.67	0.13~1
	speed	0~0.04	0.17~0.23	0.26~0.79	0.47~1	0.36~1	0.28~0.47	0.362~0.68	0.57~0.79
	accessibility	0.850	0.850	0.800	0.700	0.500	0.350	0.150	0.150
	comfort	0.500	0.500	0.450	0.900	0.850	0.750	0.850	0.850
	safety	0.500	0.400	0.100	0.350	0.350	0.700	0.850	0.850
	punctuality	0.850	0.850	0.900	0.850	0.850	0.500	0.800	0.800
Economic benefit	dynamic occupied area	0.97~0.98	0.69~0.81	0.41~0.70	0~0.41	0.20~0.61	0.93~0.97	0.990	1.000
	static occupied area	1.000	0.910	0.79~0.84	0~0.18	0.18~0.35	0.93~0.96	0.960	0.950
	passenger transport capacity	0.000	0.002	0.005	0.007	0.008	0.080	0.500	1.000
	user's expense	1.000	0.980	0.780	0.000	0.440	0.920	0.78~0.83	0.72~0.83
	energy consumption	0.894	1.000	0.532	0.000	0.213	0.883	0.957	0.979
Environment benefit	sound pollution	1.000	0.995	0.500	0.000	0.200	0.950	0.975	0.975
	air pollution	1.000	0.999	0.143	0.000	0.286	0.929	0.964	0.964
	public cost	0.850	0.850	0.100	0.300	0.300	0.500	0.700	0.700

Sub-objective: such as the traffic function

$$MaxU = \sum_{i=1}^{n} \sum_{j=1}^{m} A_{ij} X_j$$

$$s.t. \quad \sum_{j=1}^{m} X_j = 1$$

$$X_j \in [a_j, b_j]$$

where, A_{ij} ——non-dimensional value of different traffic modes corresponding to different indicators in the traffic function;

X_j ——the proportions of different traffic modes;

a_j, b_j ——the upper and lower limits of different traffic modes according to the developmental level of urban economy, urban structure, infrastructure conditions and the characteristics of resident trip demand. (They are generally got from the whole national urban analogy.) Then we use linear planning to work out the value of X_j, and ascertain the corresponding urban passenger transport structure when economic benefit and environment benefit arrive to the optimum with the same theory.

2.2 Calculation of the Correlation degree

This paper quotes the conception of associated degrees of grey theory, and uses correlation degree to represent the correlation degree of corresponding passenger transport structure between the existed and local-optimization. For a certain sub-objective (traffic function, economic benefit and environment benefit) relatively, the bigger correlation degree is, the more reasonable the existed passenger transport structure is. Calculated formulation is:

$$\gamma(x_0(k), x_i(k)) = \frac{\min_i \min_k |x_0(k) - x_i(k)| + \zeta \max_i \max_k |x_0(k) - x_i(k)|}{|x_0(k) - x_i(k)| + \zeta \max_i \max_k |x_0(k) - x_i(k)|}$$

$$P(X_0, X_i) = \frac{1}{m}\sum_{k=1}^{m} \gamma(x_0(k), x_i(k))$$

where, m ——the total of the traffic modes in the urban passenger transport structure;

$x_0(k)$ ——the proportion of traffic mode of No. k in the existed passenger transport structure;

$x_i(k)$ ——the proportion of traffic mode of NO. k when No. i sub-objective arrives to the optimum;

ζ ——distinguishing coefficient of correlation degree, $\zeta \in (0,1)$;

$P(X_0, X_i)$ ——the correlation degree of passenger transport structure ascertained by the existed passenger transport relative to No. i sub-objective arriving to the optimum.

The comprehensive evaluation includes three different sub goal items, thanks to different sub-objectives having different rate of contributions in comprehensive evaluation, and the correlation degree are calculated in terms of weight in order to reflect this kind of difference. So the formulation of comprehensive evaluation is:

$$E = \sum_{i=1}^{3} P(X_0, X_i) \cdot \omega_i$$

where, $P(X_0, X_i)$ ——the correlation degree of passenger transport structure ascertained by the existed passenger transport relative to one sub-objective arriving to the optimum;

ω_i ——the weights of sub-objectives in comprehensive evaluation;

E ——comprehensive evaluation value.

This paper uses AHP method to ascertain every sub-objective weight ω_i in comprehensive evaluation.

3. CASE STUDY

Using the foregoing evaluation method, this paper carries out comprehensive evaluation for the urban passenger transport structure of Xi'an in China. Based on materials of resident trip survey in 2000, the distributions of resident trip model of Xi'an are in Figure 2.

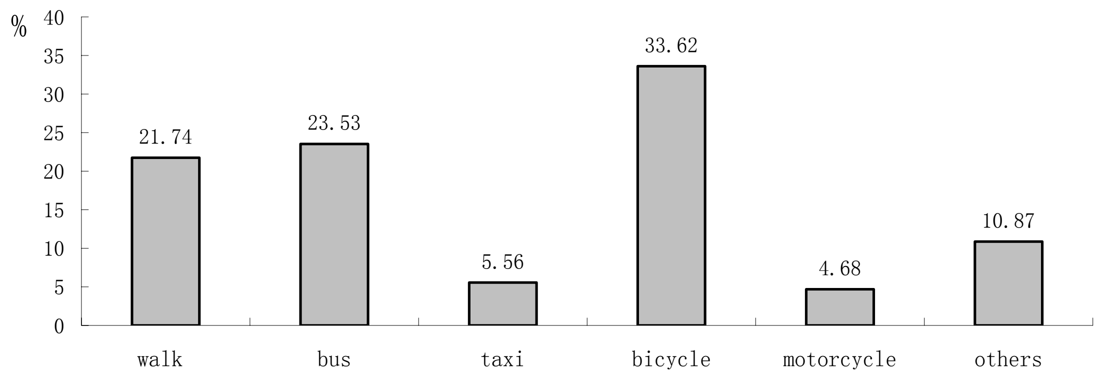

Figure 2. Distributions of Resident Trip Mode of Xi'an in China

According to the existed situation of Xi'an, this paper uses analogy method to ascertain the proportion range of different traffic modes in urban passenger transport structure referencing to national metropolis (the population is more than 2 million) like Table 4.

Table 4. Proportion Range of Passenger Transport Structure in National Metropolis/%

bus	bicycle	walk	public passenger coach	taxi	motorcycle	others
15~30	20~40	15~35	2~15	1.5~5	1~5	2~12

Based on the non-dimensional values of each traffic modes in Tab.3, this paper uses the ascertain method of urban passenger structure when the sub-objective is optimum. In the course of solving, when a value of non-dimensional indicator lies in a interval, this paper chooses the interval intermediate value, and plans to solve the passenger transport structure when traffic function, economic benefit and environment benefit respectively arrive the optimum. Because the existed situation structure includes the item of "others", this paper should adjust properly in calculating the passenger transport structure and the adjusted passenger transport structure when the sub-objectives arrive to the optimum are as follows (Table 5):

Table 5.The Optimum Passenger Transport Structure of Sub-objectives Adjusted

Sub-objectives	walk	bus	taxi	bicycle	motorcycle	others
Traffic function	0.15	0.28	0.05	0.36	0.05	0.11
Economic benefit	0.30	0.295	0.021	0.285	0.01	0.089
Environment benefit	0.285	0.215	0.015	0.37	0.01	0.105

Distinguishing coefficient ζ is 0.5 in calculating the correlation degree $P(X_0, X_i)$ of above-mentioned passenger transport structure relative to the existed passenger transport structure, and uses AHP method to ascertain the weights ω_i of sub-objectives in comprehensive evaluation.

Table 6. Correlation degree and Corresponding Weights of Sub-objectives

Sub-objectives	correlation degree $P(X_0, X_i)$	weights ω_i
Traffic function	0.6608	0.3226
Economic benefit	0.7169	0.2596
Environment benefit	0.7235	0.4178

Then the comprehensive evaluation result of urban passenger transport structure of Xi'an is $E=\sum_{i=1}^{3}P(X_0,X_i)\cdot\omega_i=0.7016$. Stipulates that if $E\geq 0.9$, the urban passenger transport structure is excellent; if $0.8\leq E<0.9$, the urban passenger transport structure is good; if $0.7\leq E<0.8$, the urban passenger transport structure is moderate; if $0.6\leq E<0.7$, the urban passenger transport structure is bad; if $E<0.6$, the urban passenger transport structure is worst. It will be easy to get that the level of Xian's urban passenger transport structure is moderate, and the passenger transport structure needs adjusting.

4. CONCLUSION

According to system analysis principle, this paper sets up the evaluation indicator system of urban passenger transport structure from three aspects: the traffic function, economic benefit and environment benefit, according to the biggest utility theory and the correlation degree theory of grey system theory, it puts forward the conception of correlation degree of the existed urban passenger transport structure relative to local-optimization structure. At last, this paper evaluates and analyses the passenger transport structure of Xi'an of China, and this method is simple and convenient. But what need to be pointed out is, when ascertaining the passenger transport structure when the sub-objectives arrive to the optimum, that the restraining conditions should be ascertained according to the existed situation of the city.

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