EVALUATING THE URBAN PUBLIC TRANSIT NETWORK BASED ON THE ATTRIBUTE RECOGNITION MODEL

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Abstract. The aim of this paper is to propose an attribute recognition model, so that it can be used to simultaneously estimate the public transit network system. Based on the analysis of a variety of factors influencing the public transit network, quantitative research has been conducted with reference to the attribute recognition theory in order to make scientific decision-making. On the basis of defining attribute measure, this paper presents the attribute recognition model suggesting the attribute recognition theory that can be used to evaluate the public transit network. The reliability of the new method can be explained using real data of the survey on the public transit network in China. The applied results offer scientific reference for instructing and controlling urban traffic by the Government. The main advantages of the new model are in contexts where internal linkage and shared inputs between activities can be considered. The structure of this mode is more realistic than that of the conventional one.

Keywords: traffic planning, urban public transit network, comprehensive evaluation, attribute recognition model.

1. Introduction

Urban public transit is one of the most critic problems in urban traffic as it involves every resident in the city. At present, urban population is increasing fast while the problem of traffic becomes more and more serious. It is valuable to assess the public transit network for urban traffic development and management (Wang and Liu 2002; Magnanti and Wong 1984; Lin 2001; Liu *et al.* 2003; Jovic 2003; Bazaras *et al.* 2008; Daunoras *et al.* 2008; Matis 2008, 2010; Saunders *et al.* 2008; Burinskienė 2009; Burinskienė and Rudzkienė 2009; Filipović *et al.* 2009; Junevičius and Bogdevičius 2009; Mesarec and Lep 2009; Paslawski 2009; Szűcs 2009; Griškevičiūtė-Gečienė 2010; Jakimavičius and Burinskienė 2009, 2010; Jović and Đorić 2010). Many different approaches have been proposed in literature. In our case, we look at three kinds of methods used to evaluate the urban public transit network. First, it is a fuzzy comprehensive evaluation method used by Yin and Li (2000) and Wang *et al.* (2002). Second, it contains data envelopment analysis (DEA) employed by Cook and Zhu (2005) and Cooper *et al.* (2006). Third, it is s grey relational evaluation method known by Hu *et al.* (2006) and Florian (1977).

First, the fuzzy evaluation method is the application of a fuzzy membership function to describe the ambiguity of public transit systems. It can objectively reflect the actual situation. However, it emphasizes the role of the extreme value and loses some useful information.

Second, based on different information and nonuniqueness of the solution theory, grey relational degree assessment is more suitable for the analysis of incomplete information, numerous indexes and some other indexes that are related or duplicated. However, computational workload is heavy and the evaluation process is complicated.

Third, the method evaluating data envelopment analysis (DEA) is multi-data quantitative evaluation based on the correlation function theory, however, it needs more data as the calculation process is complicated.

The attribute recognition theory is a new method to deal with uncertainty phenomenon (Men and Liang 2005). The attribute recognition model (ARM) is developed to evaluate an object synthetically employing difference evaluating indicators and to measure where objects for decision-making fulfil 'accept or reject' criterion. ARM, as an important part of attribute mathematics, has been successfully applied in many fields such as project investment management (Li and Ling 2004). However, classical ARM method that is built under the condition where the value of an evaluating indicator is a

real number cannot deal with the problem of the interval number. In fact, the urban public transit system is a complex one and is more and more influenced by uncertainty factors. On the one hand, the accurate values of evaluating indicators for the urban transit network are unavailable in the urban traffic system from the real world; on the other hand, a traditional evaluation method for the urban transit network is not suitable for the situation where different values of an evaluating indicator have great disparity in dimension. Considering two above introduced reasons, this paper sets up the attribute interval recognition model (AIRM) for a quantitative assessment of the urban public transit network. It seems to be more objective and reasonable to assess the public transit network having several advantages like simple, good practicality and high manoeuvrability.

2. Attribute Recognition Model

In study space X, n public transport samples $x_1, x_2, \cdots, x_n$ are used to evaluate the urban traffic system and each sample has indexes $I_1, I_2, \cdots, I_n$. n is determined by the real situation and may be one or more. However, number n does not affect evaluation results. The surveyed value of urban public transit sample x_i for index I_j is t_{ij}, so the urban public transit sample can be indicated with m-dimension vector $x_i = (t_{i1}, t_{i2}, \cdots, t_{im})$. Suppose that F is some grade attribute space and $(c_1, c_2, \cdots, c_k)$ is ordered and cut-up grade in attribute space F. So, condition $c_1 > c_2 > \cdots > c_k$ is satisfied and the grade standard of every index (Men and Liang 2005) will be known. Grade standard matrix A is shown below:

$$A = \begin{array}{c} \\ I_1 \\ I_2 \\ \vdots \\ I_m \end{array} \begin{bmatrix} [a_{11},b_{11}] & [a_{12},b_{12}] & \cdots & [a_{1k},b_{1k}] \\ [a_{21},b_{21}] & [a_{22},b_{22}] & \cdots & [a_{2k},b_{2k}] \\ \vdots & \vdots & \cdots & \vdots \\ [a_{n1},b_{n1}] & [a_{n2},b_{n2}] & \cdots & [a_{nk},b_{nk}] \end{bmatrix}, \quad (1)$$

where:

$a_{j1} > a_{j2} > \cdots > a_{jk}$ and $b_{j1} > b_{j2} > \cdots > b_{jk}$ or
$a_{j1} < a_{j2} < \cdots < a_{jk}$ and $b_{j1} < b_{j2} < \cdots < b_{jk}$.

2.1. Attribute Measure

First, we calculate attribute measurement interval:

$$[u_{ijg}] = \left[\underline{u}_{ijg}, \overline{u}_{ijg} \right]$$

for index I_j with value t_{ij} and attribute c_g $(g = 1, 2, \cdots, k)$. Suppose that $a_{j1} < a_{j2} < \cdots < a_{jk}$ and $b_{j1} < b_{j2} < \cdots < b_{jk}$.
Thus,

– if $t_{ij} < a_{j1}$, then, $\underline{u}_{ij1} = 1$, $\underline{u}_{ij2} = \cdots = \underline{u}_{ijk} = 0$ and
if $t_{ij} \le b_{j1}$, then, $\overline{u}_{ij1} = 1$, $\overline{u}_{ij2} = \cdots = \overline{u}_{ijk} = 0$;
– if $t_{ij} \ge a_{jk}$, then, $\underline{u}_{ijk} = 1$, $\underline{u}_{ij1} = \cdots = \underline{u}_{ijk-1} = 0$ and
if $t_{ij} \ge b_{jk}$, then, $\overline{u}_{ijk} = 1$, $\overline{u}_{ij1} = \cdots = \overline{u}_{ijk-1} = 0$;
– if $a_{jl} \le t_{ij} < a_{jl+1}$, then,

$$\underline{u}_{ijl} = \frac{\left| t_{ij} - a_{jl+1} \right|}{\left| a_{jl} - a_{jl+1} \right|}, \quad \underline{u}_{ijl+1} = \frac{\left| t_{ij} - a_{jl} \right|}{\left| a_{jl} - a_{jl+1} \right|},$$

$\underline{u}_{ijk} = 0$ for $k < l$ or $k > l + 1$ and
if $b_{jl} \le t_{ij} < b_{jl+1}$, then,

$$\overline{u}_{ijl} = \frac{\left| t_{ij} - b_{jl+1} \right|}{\left| b_{jl} - b_{jl+1} \right|}, \quad \overline{u}_{ijl+1} = \frac{\left| t_{ij} - b_{jl} \right|}{\left| b_{jl} - b_{jl+1} \right|},$$

$\overline{u}_{ijk} = 0$, for $k < l$ or $k > l + 1$.

The importance of every index can be identical or different. Thus, the weight of indexes needs to be considered.

2.2. Determining the Weight of Index Based Coefficient Variation

In this paper, index weight is determined by the coefficient variation of index value in the urban public transit system. On the one hand, it takes a full advantage of information on its own monitoring data. On the other, it prevents the impact of weight from different index and different measure units. It also can avoid the subjective and partial experts' opinion on giving index weight. The method is explained below.

We calculate the coefficient variation δ_{jg} of index I_j as follows:

$$\delta_{jg} = \sqrt{\frac{1}{k} \sum_{g=1}^{k} \left(t_{jg} - \overline{t}_{jg} \right)^2} \Big/ \overline{t}_{jg}, \quad (2)$$

where: δ_{jg} is the coefficient variation of index I_j; k is the number of standardization rating which is 5 in this paper k; $\overline{t}_{jg}$ is the average value of the characteristic interval $[u_{ijg}]$ of the evaluated index I_j and

$$\overline{t}_{jg} = \frac{1}{2} \left[\underline{u}_{ijg} + \overline{u}_{ijg} \right] \frac{1}{2} \left[\underline{u}_{ijg} + \overline{u}_{ijg} \right]. \quad (3)$$

We calculate the weight of index I_j as follows:

$$w_{jg} = \frac{\delta_{jg}}{\sum_{j=1}^{m} \delta_{jg}}, \quad (4)$$

where: w_{jg} is the weight of index I_j.

2.3. Synthetic Attribute Measure

Synthetic attribute measure $[u_{jg}]$ can be calculated by index weight w_{jg} determined by formula (4) and attribute measure $[u_{ijg}] = \left[\underline{u}_{ijg}, \overline{u}_{ijg} \right]$.

It can be expressed as formula:

$$[u_{jg}] = \left[\underline{u}_{jg}, \overline{u}_{jg} \right], \quad (5)$$

where:

$$\underline{u}_{jg} = \sum_{j=1}^{m} w_{jg} \underline{u}_{ijg} \text{ and } \overline{u}_{jg} = \sum_{j=1}^{m} w_{jg} \overline{u}_{ijg} \text{ for } 1 \le i \le n$$

and $1 \le g \le k$.

According to confidence degree λ, the grade of the urban public transit network can be calculated based on synthetic attribute measure:

$$k_i = \min\left\{ g : \sum_{i=1}^{g} u_{x_i}(c_i) \geq \lambda, 1 \leq g \leq k \right\},\qquad (6)$$

where: $u_{x_i}(c_i) = \frac{1}{2}\left(\underline{u}_{ji} + \overline{u}_{ji} \right)$ for $i = 1, 2, \cdots, k$.

Equation (6) means that urban public traffic sample x_i belongs to grade c_{k_i}. The value of λ is usually 0.6.

Based on score criteria, we calculate:

$$q_{x_i} = \sum_{j=1}^{k} n_j u_{x_i}(c_j).\qquad (7)$$

According to comprehensive evaluating value q_{x_i}, we compare and sequence sample x_i. Value q_{x_i} reflects a 'good' or 'bad' urban public transit network which provides the scientific basis of decision-making for urban public transit development. When value q_{x_i} is greater, the urban public transit network is better.

3. The Evaluation Index System of the Urban Public Transit Network

The urban public transit network system is a multiple system of service functions. The main purposes of assessing the urban public transit network are to increase travel accessibility for residents, reasonably adjust urban transport structure and promote sustainable development for urban transportation. Therefore, the evaluation index system should reflect the connotation of the urban public transit network. It should also reveal the spatial distribution and structure of the urban public transit system indicating its functional level, including all aspects of the impact factors on the urban public transit system.

According to urban public transit characteristics, we describe the public transit network from two aspects – passengers and a public traffic company. Passengers hope for an efficient public transit system that is convenient, fast, comfortable and cheap, whereas the company is restricted by the cost embracing drivers, conducts, buses, roads and financial capacity which cannot make passengers completely satisfied. Based on passenger and company benefits, this paper chooses the evaluation index for urban public transit able to satisfy both a passenger and a company.

3.1. Selection of the Evaluation Index

The choice of the evaluation index is very important to evaluate the public transit network. The index will not only affect the size of the overall workload but also affect the reliability of evaluation results. Because a comprehensive evaluation of the public transit network system contains multi-index and multi-attribute questions, the choice of evaluation indexes should follow the principles below:

- *Feasibility principle.* Evaluation indexes should reflect the real situation of the public transit network system and require a clear evaluation concept, acquirable data and better manoeuvrability.
- *Simple principle.* Evaluation indexes should be as simple as possible.

- *Representation principle.* Evaluation indexes should be the main and representative indexes of the public transit network.
- *Comparability principle.* In order to easily compare different indices, it requires that evaluation indexes have commensurability in time and space.
- *Comprehensiveness principle.* One index can only reflect the situation for the public transit network system from one side and cannot reflect the total situation of the traffic system. Nevertheless, the evaluation index system should make effort to totally reflect the public traffic system for evaluation objects.

Urban traffic is a large system which includes many factors, so it is impossible to cover all of them, and therefore we must choose some factors as evaluating indexes. According to basic connotation and design principles of the urban public transit network used at home and abroad, the public transit network index system is established as shown in Fig. 1. I_1 is the provided density of vehicle kilometre; I_2 is the density of the public transit network; I_3 is the possessing rate of a public transit vehicle; I_4 is bus stop density; I_5 is average stop distance; I_6 is on-schedule-time rate; I_7 is load factor on-peak-time; I_8 is line load factor on-the-whole-day; I_9 is average walking time; I_{10} is average transfer rate;; I_{11} is the frequency of passenger travel by bus in a year; I_{12} is 100-vehicle-km cost; I_{13} is line overlap factor; I_{14} is operating income; I_{15} is overall labour productivity; I_{16} is the coordination degree of land-use; I_{17} is the development adaptability of transit network; I_{18} is a degree of reducing traffic congestion; I_{19} is the benefit of saving time; I_{20} is the sharing rate of the public transit network.
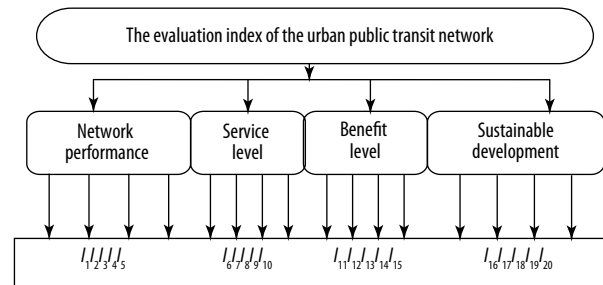

Fig. 1. The evaluation index system of the urban public transit network

3.2. The Inspection Criterion for the Evaluation Index

Based on the screening criterion for the evaluation index system of urban public transit and with reference to concerning research results and relevant experts' advice at home and abroad, this paper designs the inspection criterion for five grades of strength or weakness to describe the degree of the practicality of each evaluation index under each selecting principle. Twenty evaluation indexes of the urban public transit network show difference in strength or weakness by '+' and '–' respectively in each selecting principle (see Table 1).

Table.1. The test principle of the evaluation index

Indexes	FP	CP	RP	SP	CPP
I_1	+ + + – –	+ + + + –	+ + + + –	+ + – – –	+ + + – –
I_2	+ + + – –	+ + + – –	+ + + + –	+ + + + –	+ + + + –
I_3	+ + + + –	+ + + + –	+ + + – –	+ + + – –	+ + + – –
I_4	+ + + + –	+ + + – –	+ + + – –	+ + + – –	+ + + + –
I_5	+ + – – –	+ + + – –	+ + + + –	+ + + – –	+ + + + –
I_6	+ + + – –	+ + – – –	+ + + – –	+ + – – –	+ + + + –
I_7	+ + + + –	+ + + – –	+ + + + –	+ + + – –	+ + + + –
I_8	+ + + + –	+ + + + –	+ + + + –	+ + + – –	+ + + – –
I_9	+ + – – –	+ + – – –	+ + + – –	+ + + – –	+ + + + –
I_{10}	+ + + – –	+ + + – –	+ + + – –	+ + + – –	+ + + + –
I_{11}	+ + + – –	+ + + + –	+ + + + –	+ + + – –	+ + + + –
I_{12}	+ + – – –	+ + + + –	+ + + – –	+ + + – –	+ + + – –
I_{13}	+ + + + –	+ + – – –	+ + + – –	+ + + – –	+ + + – –
I_{14}	+ + + – –	+ + + – –	+ + + – –	+ + – – –	+ + + – –
I_{15}	+ + + + –	+ + + + –	+ + – – –	+ + – – –	+ + + – –
I_{16}	+ + – – –	+ + – – –	+ + + + –	+ + + – –	+ + + – –
I_{17}	+ + + – –	+ + + + –	+ + + + –	+ + – – –	+ + + – –
I_{18}	+ + + + –	+ + + – –	+ + – – –	+ + + – –	+ + – – –
I_{19}	+ + + – –	+ + + + –	+ + + – –	+ + – – –	+ + – – –
I_{20}	+ + + – –	+ + + – –	+ + + – –	+ + – – –	+ + – – –

FP is feasibility principle; CP is comparability principle;
RP is representation principle; SP is simple principle;
CPP is comprehensiveness principle

3.3. The Quantitative Processing of the Evaluation Index

The quantitative treatment of evaluation indexes plays a major role in the evaluation process. We quantify the evaluation indexes of the public transit network from a practical point of view.

In general, there are benefit indexes and cost indexes in evaluating problems and the 'dimension' of different indexes may be different. In order to measure all indexes in dimensionless units, we can normalize the value of each index.

3.3.1. The Normalization Method for the Quantitative Index

In our case, we adopt the membership function in fuzzy mathematics to normalize data on the quantitative index where:

– the membership function for cost indexes:

$$\delta_i = u_{d_i}(x_i) = \begin{cases} 1, & x_i \le m_i, \\ \dfrac{M_i - x_i}{M_i - m_i}, & x_i \in d_i, \\ 0, & x_i \ge M_i, \end{cases} \tag{8}$$

– the membership function for benefit indexes:

$$\delta_i = u_{d_i}(x_i) = \begin{cases} 0, & x_i \le m_i, \\ \dfrac{x_i - m_i}{M_i - m_i}, & x_i \in d_i, \\ 1, & x_i \ge M_i, \end{cases} \tag{9}$$

– the membership function for moderate indexes:

$$\delta_i = u_{d_i}(x_i) = \begin{cases} \dfrac{x_i - m_i}{E(d_i) - m_i}, & x_i \in (m_i, E(d_i)), \\ \dfrac{M_i - x_i}{M_i - E(d_i)}, & x_i \in (E(d_i), M_i), \\ 1, & x_i \ge M_i \; or \; x_i \le m_i. \end{cases} \tag{10}$$

where: $d_i = \left[m_i, M_i \right]$ is range, and $E(d_i)$ is the expected value for the evaluation index in range d_i.

3.3.2. The Normalization Results for the Qualitative Index

In our case, to normalize the qualitative index, we use the fuzzy language of mathematics as shown in Table 2.

Table 2. Quantification of evaluation indice

Criterion	Evaluation interval
Excellent	[0.9,1.0]
Good	[0.8,0.9]
Moderate	[0.7,0.8]
General	[0.6,0.7]
Poor	[0.5,0.6]

4. Application

In order to accurately describe the overall level of the urban public transit system and give an intuitive and overall conclusion to decision-makers, the paper carries out comprehensive evaluation applying the attribute recognition model based on the quantitative analysis of evaluation indexes. Data used in this paper were taken from our survey on traffic conducted in one of Chinese cities in June / July 2005 (see Fig. 2).

Suppose that evaluation set:

c_1 ={ Grade I| Excellent}; c_2 ={ Grade II| Good};

c_3 ={ Grade III| Moderate}; c_4 ={ Grade IV| General};

c_5 ={ Grade V| Poor}.

Each urban public traffic sample x_i has been measured using evaluation indexes $I_1, I_2, \cdots, I_{20}$. According to their influence on urban public traffic, evaluation results have different grades to measure the urban public transit system (Zhou and Yang 2004; Zavadskas *et al.* 2007). This paper should divide evaluation results into five grades considering compressive factors, namely grades I, II, III, IV and V, as shown in Table 3.

Fig. 2. The urban transit network in one of the cities

Table 3. The grade interval of the evaluation index

Index	c_1	c_2	c_3	c_4	c_5
I_1	[0.3,0.45]	[0.45,0.55]	[0.55,0.70]	[0.7, 0.85]	[0.85,1.0]
I_2	[5,10]	[4,5]	[2.5,4]	[1.2,2.5]	[0,1.2]
I_3	[13,20]	[10,13]	[7,10]	[5,7]	[0,5]
I_4	[0.6,1]	[0.55,0.6]	[0.48,0.55]	[0.43,0.48]	[0,0.43]
I_5	[10,15]	[7.5,10]	[5.0,7.5]	[2.5,5.0]	[0,2.5]
I_6	[0,20]	[20,25]	[25,35]	[35,48]	[48,60]
I_7	[85,100]	[75,85]	[65,75]	[50,65]	[0,50]
I_8	[0,1.15]	[1.15,1.35]	[1.35,1.48]	[1.48,1.60]	[1.60,2.0]
I_9	[0,0.65]	[0.65,0.75]	[0.75,0.85]	[0.85,0.95]	[0.95,1.0]
I_{10}	[0,0.55]	[0.55,0.65]	[0.65,0.75]	[0.75,0.85]	[0.85,1.0]
I_{11}	[380,500]	[280,380]	[180,280]	[100,180]	[0,100]
I_{12}	[90,100]	[80,90]	[65,80]	[50,60]	[0,50]
I_{13}	[0,10]	[10,20]	[20,30]	[30,40]	[40,100]
I_{14}	[80,100]	[70,80]	[60,70]	[50,60]	[0,50]
I_{15}	[1.0,1.25]	[1.25,1.5]	[1.5,1.75]	[1.75,2.25]	[2.25,5]
I_{16}	[80,100]	[70,80]	[60,70]	[50,60]	[0,50]
I_{17}	[90,100]	[80,90]	[70,80]	[55,70]	[0,55]
I_{18}	[85,100]	[75,85]	[65,75]	[50,65]	[0,50]
I_{19}	[28,100]	[25,28]	[20,25]	[17,20]	[0,17]
I_{20}	[22,50]	[17,22]	[14,17]	[10,14]	[0,10]

Evaluation space x has one element (that is to say, there is one city), so $n = 1$. Based on formulas from (8) to (10) and data collected by a study group, the calculated values of twenty evaluation indexes for one city are:

$$x = (0.53, 2.78, 8.1, 0.51, 6.8, 30, 68, 1.41, 0.81,$$
$$0.69, 189, 73, 27, 66, 1.73, 65, 76, 77, 26, 15).$$

Step 1. Determining the weight coefficient
According to formula (4), the evaluated index weight can be calculated as

$$w = (0.041, 0.049, 0.051, 0.059, 0.053, 0.047,$$
$$0.042, 0.058, 0.046, 0.048, 0.052, 0.054, 0.043,$$
$$0.053, 0.051, 0.056, 0.057, 0.046, 0.049, 0.044).$$

Step 2. Calculating attribute measure
Attribute measure can be calculated using data x and formula (5) as

$\underline{u}_{11} = 0.373$, $\underline{u}_{12} = 0.281$, $\underline{u}_{13} = 0.162$, $\underline{u}_{14} = 0.157$, $\underline{u}_{15} = 0.018$,

$\overline{u}_{11} = 0.428$, $\overline{u}_{12} = 0.332$, $\overline{u}_{13} = 0.272$, $\overline{u}_{14} = 0.212$, $\overline{u}_{15} = 0.198$.

Step 3. Determining the average value
The paper obtained attribute measure $[u_{jg}]$ using equation $\tilde{u}_{jg} = \frac{1}{2}(\underline{u}_{jg} + \overline{u}_{jg})$. Then,

$\tilde{u}_{11} = 0.401$, $\tilde{u}_{12} = 0.307$, $\tilde{u}_{13} = 0.217$, $\tilde{u}_{14} = 0.185$, $\tilde{u}_{15} = 0.108$.

Step 4. Determining the evaluation value
According to the criterion of confidence degree and formula (6) where λ is 0.6, $k_i = 3$.

$$\text{Grade} = \min\left\{ g : \sum_{l=1}^{g} u_{x_i}\left(c_l\right) \geq 0.6, 1 \leq g \leq 5 \right\}.$$

Table 3 shows that the urban public traffic system belongs to 'grade III' in one city, namely 'Good' condition, which corresponds to the evaluation results of a multi-specialist (Wang *et al.* 2002; Hu *et al.* 2006). Thus, the author believes it is basically rational as it serves as an example of how to raise the level of sustainable development considering the urban public transit network in this city.

5. Conclusions

1. The paper has improved the evaluation model of attribute recognition and set up the evaluation model of attribute recognition. The new model differs from the conventional one in two respects. First, the weight of the evaluated indexes is determined by the variation coefficient of the evaluated index value. Second, arithmetic can solve the problem in which the evaluating value is the interval number. Such situation allows the evaluation results of the urban public transit network to be more objective, rational and scientific which is very important for guiding the further development of the public transport system.

2. An example is given to illustrate the rationality of attribute interval recognition model (AIRM) and the validity of relational arithmetic. The evaluation results of the attribute recognition model can directly reflect the current situation of the urban public transit system and has certain comparability in space. Hence, the presented new model is feasible for a synthetic evaluation of urban public traffic and provides a scientific basis for making a policy decision on traffic construction. Meanwhile, it provides a number of new ideas for the evaluated method. We suppose that in the future, an interest in developing more efficient methods based on this idea will be growing.

Acknowledgements

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