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Evaluation on Transfer Efficiency at Integrated Transport Terminals through Multilevel Grey Evaluation

Yan Leng[a,*], Chunge Kou[a], Naihui Zhou[a], Qing Li[a], Yanjiao Liang[a], Zichuan Xu[a], Shaokuan Chen[b]

[a] *School ofTraffic and Transportation, Beijing Jiaotong University , Beijing,China*
[b] *School of science, Beijing Jiaotong University ,Beijing,China*

Abstract

Transfer efficiency in integrated transportation terminal is greatly important for both passengers and operational companies. In this paper, we proposed various criteria and a hierarchy index system to evaluate the performance of the transfer condition inside Beijing South Railway Station. To make the assessment more scientific, we assign weightings to each of them by integrated weighting method. Then we use an evaluation method, Multi-level Grey Evaluation, to calculate the performance indexes of different transfer modes in the station and further we compare the ranking results of transfer efficiency of different transfer modes.

Keywords: integrated transport terminals; MCDA; multi-level grey evaluation method

1. Introduction

The importance of transfer efficiency in an integrated transportation terminal to both passengers and operational companies is undoubtedly obvious. Traditionally, people use single-object problem as an acknowledged methodological approach to provide an assessment of the performance of the

* Corresponding author. Tel.: 8610-013466545545.

E-mail address: alexlius@yahoo.cn.

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transportation terminals. One well common method applied in evaluating transportation terminals is cost-benefit analysis, which mainly assesses the monetary scale of transportation terminals (Ricardo, 2008). However, an assessment based solely on one specific impacts of integrated transportation terminals, monetary or non-monetary, is insufficient because the complicated impacts of other equally of even more significant factors also influence the performance of the transfer efficiency (Chris,2008; Barfod, 201 1). With the development of urban transportation management and control system, people have to inspect transportation terminals with a broader perspective (Sailing, 2007). Actually, a scientific evaluation on integrated transportation terminals involves multitude indexes including technical, social, economic, environmental aspects.

The application of multi-criteria decision analysis (MCDA) can, in this context, be regarded as an scientific tool to assess the performance of the complicated procedure (Michael, 2012). Actually, integrated transportation terminals are complex systems, the performances of which are usually defined by multitude conflict alternatives. Therefore, a multi-criteria decision analysis is applied to cope with this complicated process which requires a formal and comprehensive analysis (N Fenton, 2001).

2. Crucial index for evaluation

The purpose of the evaluation index system (EIS) is to provide a scientific evaluation of the integrated transportation terminals to realize the comprehensive evaluation of multiple variables in the multi-level transportation interface system. As is known to all, the major function of integrated passenger transport terminals is to provide convenient and comfortable transfer services for passengers. Therefore, the establishment of an evaluation index system should follow the principle of user satisfaction, which is to meet passengers' requirements of convenient, continuous travel as well as to achieve the largest social benefits for the operational company whether in quantitative or qualitative aspects (Zhou, 2007). Therefore, the establishment of the ESI should combine macroscopically and microscopically different indexes. From macroscopic viewpoint, ESI should take the overall layout of hubs into account while from microscopic one it should focus on the issues of the connection of facilities and transportation organization. We further divide all the indexes defined in this paper into three types: {*H, M, L*} in equivalence to {the higher the better, certain middle number is the better, the lower the better}. Fig. 1 denotes the hierarchy structure of criterions with the title, description and its type.

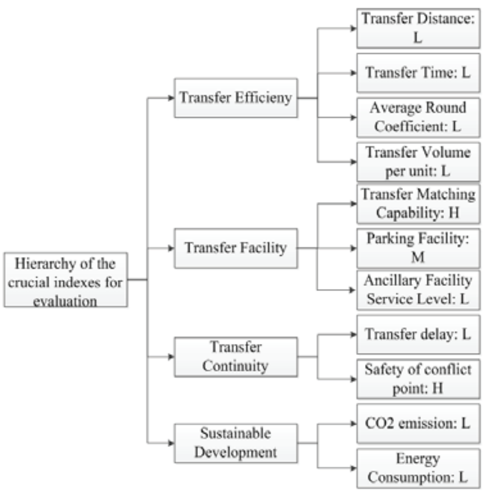

Fig. 1. Hierarchy of the crucial indexes for evaluation

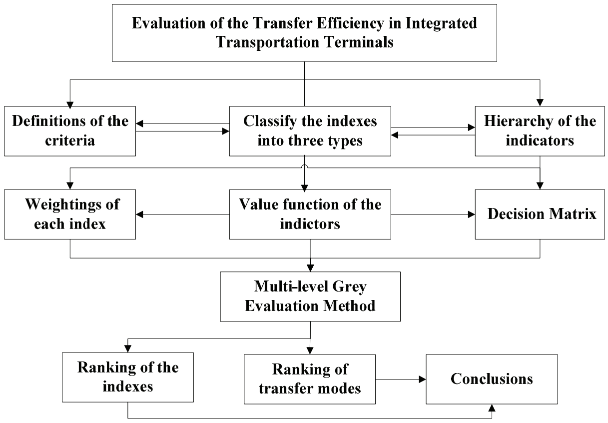

Fig. 2. Flowchart for the proposed methodology

3. Evaluation methods

We develop an evaluation method of transfer efficiency in integrated transportation terminals. Firstly, we define numerous criteria and construct a hierarchy framework of indexes, which has been demonstrated in Section 2. Secondly, we formulate the decision matrix by the data from investigation of certain transportation terminals. With the decision matrix obtained, we further calculate the weights of each index. Further, we apply Multi-level Grey Evaluation Method to evaluate the transfer efficiency of terminals. Finally, we attain the rankings of performance indexes for different transfer modes. The flowchart of the methodology is shown in Fig. 2.

3.1 Determination of the weights: Integrated weight method

In statistics and its practice, the weighting is an invaluable indicator that measures the importance of each criteria or evaluation. At some point, it is both random and fuzzy. In a comprehensive evaluation, a weighting can be defined as the relative contribution a factor has made to the whole, that is, the extent to which a factor can represent the whole (Edwin, 2011). There are various ways to decide the weightings, but they all fall into two categories, subjective and objective weighting methods. The former uses subjective judgment from an evaluation team while the latter uses real data to reflect objective information. Common methods for subjective weighting are expert consultation (Delphi method), Analytical Hierarchy Process, etc. Objective weighting methods include entropy method, factor analysis, and principle component analysis. These two categories of weighting methods both have their strengths and weaknesses. An ideal weighting can be determined by combining these two methods. We have chosen an integrated weighting method to achieve this goal. The framework of the method is shown in Fig. 3. (1) Subjective weighting method: Theory and method of order relation analysis. A common way of determining subjective weights is Analytical Hierarchy Process. However, it would be much complicated if we have to compare the value of n criteria for $n(n\text{-}1)/2$ times. Consequently, we have decided to apply the order relation method being more practical through sequencing all the criteria at one time by importance, getting the relevant value of importance and eliminating the consistency check. In this process, we define the weighting of subjective weighting method as

$$W' = (w_1', w_2', \ldots, w_n') \text{ , } 0 \le w_i' \le 1, \sum_{i=1}^{n} w_i' = 1$$

Letter α indicates the importance of subjective weighting method.

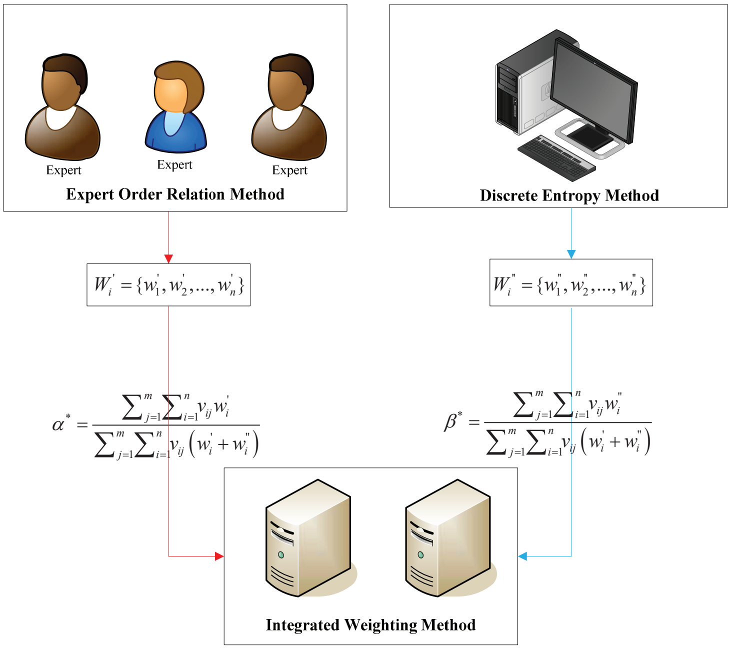

Fig. 3. Integrated weighting method

(2) Objective weighting method: Theory and method of discrete entropy method. The obtaining of entropy means the loss of information. When defining weight, the bigger the difference between two criteria, the higher the entropy. By applying the discrete entropy method, we can deduce the level of discrepancy between the criteria, thus determining the weight. In the process, we define the weight of subjective weighting method as

$$W''=(w_1^{''},w_2^{''},...,w_n^{''}),0\le w_i^{''}\le 1,\sum_{i=1}^{n}w_i^{''}=1.$$

Letter β indicates the importance of objective weighting method.

(3) Theory and process of integrated weight method. We can solve this multiple objective programming problem with the Lagrange function. The formulas are as follows.

$$\alpha^*=\frac{\sum_{j=1}^{m}\sum_{i=1}^{n}v_{ij}w_i^{'}}{\sum_{j=1}^{m}\sum_{i=1}^{n}v_{ij}\left(w_i^{'}+w_i^{''}\right)} \tag{1}$$

$$\beta^*=\frac{\sum_{j=1}^{m}\sum_{i=1}^{n}v_{ij}w_i^{''}}{\sum_{j=1}^{m}\sum_{i=1}^{n}v_{ij}\left(w_i^{'}+w_i^{''}\right)} \tag{2}$$

s.t.

$$\alpha^2+\beta^2=1 \tag{3}$$

$$d_i=\sum_{i=1}^{n}v_{ij}W_i=\sum_{i=1}^{n}v_{ij}\left(\alpha W^{'}+\beta W^{''}\right), j=1,2,...m \tag{4}$$

where v_{ij} is the value of each criteria. Here, *m* stands for the number of criterion and *n* represents the number of transfer modes.

3.2 Multi-level grey evaluation method

The multi-level grey evaluation method tend to evaluate the qualitative indicators, the advantage is that its sample size is no specific requirements, not subject to any distribution (Tung, 2010; Zhai, 2009).

The steps of multi-level grey evaluation method are as follows (Xu,2011).

Step 1: Select the reference series. Take the optimal value of each evaluation index as the entity of the reference series:

$$A_0 = \left(v_{01}, v_{02}, \ldots, v_{0i}\right),\ \ v_{0i} = Optimum\left(v_{ji}\right), i = 1,2,\ldots,n; j = 1,2,\ldots m.$$

For an evaluation system that composed by *m* evaluation units and *n* evaluation indexes, we can get the following matrix, where v_{ji} is the i^{th} evaluation index of the j^{th} alternative.

$$V = \left(v_{ji}\right)_{m\times n} = \begin{bmatrix} v_{11} & v_{12} & \cdots & v_{1n} \\ v_{21} & v_{22} & \cdots & v_{2n} \\ \vdots & \vdots & & \vdots \\ v_{m1} & v_{m2} & \cdots & v_{mn} \end{bmatrix}$$

Step 2: Normalization of the evaluation index value:

In order to make the different evaluation indexes can be compared, we need to normalize each evaluation index. The formula is as follows.

$$x_{ji} = \frac{v_{ji} - \min_j v_{ji}}{\max_j v_{ik} - \min_j v_{ji}} \tag{5}$$

Then the normalized matrix is given as below.

$$X = \left(x_{ji}\right)_{m\times n} = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{22} & \cdots & x_{2n} \\ \vdots & \vdots & & \vdots \\ x_{m1} & x_{m2} & \cdots & x_{mn} \end{bmatrix}$$

Step 3: Calculate the correlation coefficient.

Take the normalized series $X_0 = \left(x_{01}, x_{02}, \cdots, x_{0n}\right)$ as the reference series, $X_j = \left(x_{j1}, x_{j2}, \cdots, x_{jn}\right), j = 1,2,\cdots,m,$ as the compare series. Then the formula of correlation coefficient is as follows. Where ρ is the coefficient, $\rho \in [0,1]$, while in general $\rho = 0.5$.

$$\zeta_{ji} = \frac{\min_j \max_i \left|x_{0i} - x_{ji}\right| + \rho \max_j \max_i \left|x_{0i} - x_{ji}\right|}{\left|x_{0i} - x_{ji}\right| + \rho \max_j \max_i \left|x_{0i} - x_{ji}\right|}, i = 1,2,\cdots,n; j = 1,2,\cdots,m. \tag{6}$$

Then we can get the correlation coefficient matrix.

$$E = \left(\zeta_{ji}\right)_{m\times n} = \begin{bmatrix} \zeta_{11} & \zeta_{12} & \cdots & \zeta_{1n} \\ \zeta_{21} & \zeta_{22} & \cdots & \zeta_{2n} \\ \vdots & \vdots & & \vdots \\ \zeta_{m1} & \zeta_{m2} & \cdots & \zeta_{mn} \end{bmatrix}$$

where ζ_{ij} is the correlation coefficient between the j^{th} alternative unit i^{th} evaluation index and the optimal evaluation index.

Step 4: Calculate the correlation degree of single-level evaluation indexes. Taking the importance of different evaluation indexes into account, so we take the weight multiplied by the correlation coefficient as the calculation method of correlation degree. We can get the weightings from the above chapter. Thus, the calculation method of correlation degree is followed as below.

$$R=\left(r_i\right)_{1\times m}=\left(r_1,r_2,\cdots,r_m\right)=WE^T \quad (7)$$

Finally, we can get the result according to sort the correlation degree $r_i\left(i=1,2,\cdots,m\right)$.

4. Numeric cases

The Beijing South Railway Station is located in the intersection of three urban districts of Beijing, the Xicheng District, the Dongcheng District and the Fengtai District. Formerly as the Yongdingmen Railway Station, it is now one of the first major passenger transportation terminals that have been constructed and put into operation in China. It features the express inter-city bullet train to Tianjin, which travels at a top speed of 350km/hr. It also hosts the Beijng-Shanghai high-speed railway, normal-speed railway and city metro, bus, taxi and more modes of transportation. Passengers can interchange into other modes of transportation without walking out of the station. This station is a major three-dimensional transportation hub, with a five-floor vertical structure. The five floors are 2nd floor elevated waiting hall, the ground floor platform and track, the basement interchange hall, the underground subway line 4 platform and third floor underground subway line 14 platform (yet not be open). This chapter presents the numeric results of Beijing South Railway Station with the application of the method presented in the former part of this paper.

With the application of integrated weight method, we obtain the results of the evaluation in this paper. We investigate the data of internal transfer conditions and analyze them according to the issues presented in Table 1 and further obtain the following decision matrix.

Table 1. The meaning of each letter

Letter	Origin	Destination
A	Bus	Subway
B	Bus	High-speed rail
C	High-speed railway	Subway
D	High-speed railway	Bus
E	High-speed railway	Taxi
F	Taxi	High-speed rail
G	Subway	High-speed rail
H	Subway	Bus

Table 2 illustrates the value of the decision matrix and weightings determined by the data from the field investigation. The last line of the table is the weightings, while ‘W’ represents ‘weighting’.

According to the process shown above, including selecting references series, normalizing the matrix, calculating the coefficient correlation and correlation degree. We also acquire the ranking of the transfer modes determined by Multi-level Grey Analysis and the results presented in Table 3.

Table 2. Value of the decision matrix

	Transfer Distance	Transfer Time	Average round	Volume per unit time	Matching capability	Park facility	Ancillary Facility service level	Transfer delay	Safety	CO_2	Energy
A	313	175	1.2539	21.0167	0.23035	0.0324	0.56113	1.27027	0.6298	0.4408	0.907
B	524	377	1.0519	34.2667	0.09214	0.4035	0.51400	1.04312	0.3802	0.3300	2.369
C	276	91	1.2166	59.1000	0.47535	0.3741	0.19478	1.25833	1.0000	0.1108	1.946
D	248	175	1.0850	35.4667	1.42604	0.4035	0.53213	1.29091	0.7415	0.3300	2.369
E	117	86	1.0734	19.5167	3.42250	0.3790	0.00000	1.13137	1.0000	151.27	10.224
F	106	78	1.0495	29.2333	0.04872	0.3790	0.00000	1.00859	1.0000	151.27	10.224
G	640	358	1.0685	33.8500	0.11289	0.3741	0.53846	1.04251	1.0000	0.1108	1.946
H	351	175	1.4060	33.8833	0.84667	0.0324	0.56113	1.18182	0.5845	0.4408	0.907
W	0.126	0.173	0.101	0.112	0.129	0.059	0.075	0.038	0.056	0.082	0.050

Table. 3 Numeric results of multilevel grey evaluation method

Transfer modes	Correlation Degree by Multi-level Grey Evaluation Method	Multi-level Grey Evaluation Method
A	0.570084122	8
B	0.592223865	6
C	0.722802663	2
D	0.670968494	4
E	0.736566223	1
F	0.701203019	3
G	0.616659625	5
H	0.571522083	7

5. Conclusions

In this work, we combine integrated weighing and multi-level grey evaluation to develop a scientific and efficient method to assess transfer efficiencies of integrated transport terminals. Further, we apply it to evaluate the transfer efficiencies of different traffic models in the case study of the Beijing South Railway Station. From the study, we draw the conclusions as below.

1) The transfer efficiency of integrated transport terminals is a grey system with inaccurate and incomplete information. With the application of multi-level grey evaluation method, we can enlarge the source of the information and therefore improve the confidence of evaluation results.

2) Through the analysis on the ranking of the transfer modes, transfer services of bus to subway, bus to high speed rail, subway to high speed rail and subway to bus are suggested to be improved.

a) The average round coefficient of bus to subway is suggested to be lowered by 20%. The transfer delay is also decreased further. Equipping Beijing South Railway Station with more ancillary facilities is suggested.

b) The matching capability of bus to high speed rail is suggested to be improved by coordinating the arrival and departure of bus and high-speed rail.

c) The transfer distance of subway to high-speed rail is suggested to be shortened. Much effort would be made to improve transfer distances since Beijing South Railway Station has already been operated.

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