Evaluation Method of Transfer and Connection Capacity of Rail Transit Terminal

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Abstract—This paper puts forward the ideas and methods for evaluating the transfer and connection ability of multi-mode rail transit, including high-speed railway, inter-city railway, regional railway and urban rail transit. In the first place, based on the transfer station, the transfer process of passenger flow is analyzed. After that, there are three ratios taken as calculation indexes which are the ratio of transport capacity to transport capacity, service facilities capacity to transport capacity, waiting time to transfer process time. In the end, a crucial step, the transfer capacity of rail transit terminal is calculated by using the entropy weight and TOPSIS method. In summary, a set of methods and procedures for evaluating the transfer and connection capacity of rail transit terminal are obtained, and an example is given to illustrate the transfer system to the subway system of Chengdu East Passenger Transport station on a certain day.

1. INTRODUCTION
Since the beginning of the 13th five year plan, the development of rail transit is facing a new situation. With the rapid expansion of high-speed railway network, the gradual development of intercity, metropolitan and suburban railways, and the expansion of urban rail transit construction, China's rail transit will begin to enter a new pattern of complementary and coordinated development of national railway, intercity railway, metropolitan rapid rail, subway and other systems. It is an important node of the network that multiple modes of rail transit form the most direct connection at the terminal, but there are great differences in facilities, equipment, transportation organization, etc. Therefore, it is necessary to put forward the evaluation method of transfer and connection capacity of rail transit terminal to measure the current situation of transfer and connection capacity and provide basis for strengthening the transfer and connection capacity of multi system rail transit at the terminal.

At present, the representative literatures related to terminal transfer connection ability and evaluation are as follows: Reference [1] analyzes the impact of time on transfer connection, and only within a certain time range is the appropriate transfer time. In reference [2], it proposes that the transfer time is related to the departure interval of arrival and departure trains. Reference [3] studies the influence of departure time interval and train capacity on the transfer time of multimodal passengers. Reference [4] studies the function and scale of transfer and connection facilities. Reference [5] analyzes transfer problems from two aspects of equipment connection and organization coordination. Reference [6] analyzes the operation plan, arrival passenger flow rule and transfer streamline of high-speed rail and metro trains, and divides the transfer system facilities into three types: connection type, service type and waiting type to calculate the carrying capacity. Reference [7] analyzes the passenger's transfer behavior, transfer time and transfer facility configuration, and discusses the operation organization method of transfer and connection facilities from two aspects of capacity matching and dispatching coordination.
Reference [8] and [9], AHP is used to evaluate the connection of passenger transport and terminal transfer. Reference [10] combines with the characteristics of passenger flow and spatial-temporal distribution of transportation capacity of the line, three indexes, i.e. average full load rate, average waiting time and ride comfort, are adopted at the line level to establish the comprehensive matching evaluation model of transportation capacity based on EWM-TOPSIS (the entropy weight and TOPSIS method).

To sum up, scholars at home and abroad mainly focus on the optimization of transfer time or the improvement of service facilities configuration, while the comprehensive consideration of transport organization and facilities and equipment capacity evaluation is less explored, and the commonly used evaluation methods are greatly interfered by subjective factors. In view of this, this paper puts forward a new idea for the evaluation of transfer connection capacity. First, the whole process of terminal transfer is analyzed, and the practical factors such as passenger flow characteristics, transport organization mode, terminal facilities and equipment configuration and transfer streamline layout are considered comprehensively. Then the transfer train transport capacity to volume ratio, service facility capacity to volume ratio and waiting time to transfer process time ratio which can reflect the relevant relationship are selected as the evaluation indexes. Subsequently the EWM-TOPSIS method which can highlight the order of index data and can reduce the subjectivity of evaluation is utilized to evaluate the transfer connection capacity. Finally the case analysis of rail transit terminal transfer is carried out to verify effective.

2. PROBLEM DESCRIPTION

The passenger flow arrives at the terminal with the train flow of rail transit, and then disperses from the terminal with the new train flow after the transfer in the station. There is a change process from train flow to passenger flow to train flow. Specifically: passengers arrive at the station along with the train flow, realize the conversion of arriving train flow and arriving passenger flow through the full load rate, realize the conversion of arriving passenger flow and changing passenger flow through the transfer ratio, realize the transfer process through the service facilities and equipment in the transfer streamline, and finally leave the station along with the departure train flow, complete the whole process of the conversion of train flow, passenger flow and train flow in the transfer terminal, as shown in Figure 1.

![Figure 1. Transfer streamline of railway to subway.](image)

Passenger flow go through service facilities of each transfer link in the terminal. According to the service characteristics of facilities and equipment in the transfer link, it can be divided into service link, connection link and waiting link. The service link includes ticket selling, security check, ticket checking and other subsystems. The connection link includes channels, stairs, escalators and other subsystems. The waiting link includes waiting hall, platform and other subsystems. It is more convenient to calculate facility scale, capacity and transfer time according to its characteristics by dividing service facility subsystem by links, as shown in Figure 2. However, with the different transfer lines, the series parallel connection of service links is also different. Therefore, when aiming at the transfer link of a terminal, it is necessary to analyze the series parallel relationship among the links according to the transfer mode, as shown in Figure 3.
3. MODEL ALGORITHM

3.1. Model Parameters

For the convenience of description, the parameters involved in the model are listed as follows:

| Parameter | Meaning                                      | Parameter | Meaning                                      |
|-----------|----------------------------------------------|-----------|----------------------------------------------|
| \( i \)   | The i-th arrival train                       | \( T_{re} \) | Transfer process time (s)                    |
| \( j \)   | The j-th departure train                     | \( T_w \) | Waiting time (s)                             |
| \( k \)   | The k-th service facilities for transfer     | \( m \)   | Index number                                 |
| \( B_{ij} \) | Ratio of transport capacity to capacity of transfer train | \( n \) | Number of periods                            |
| \( Q_o \) | Change passenger flow (person)              | \( P_{ij} \) | Frequency                                    |
| \( \beta_i \) | Proportion of arrival                        | \( E_i \) | Information entropy                          |
3.2. Selection of Evaluation Indicators

3.2.1. Ratio of transfer train transportation capacity to traffic volume.
The ratio of transfer train capacity to traffic volume is the key index to reflect whether passengers can complete the transfer. The calculation formula is as follows:

$$B_y = \frac{Q_y}{\beta_y E_j} \quad (1)$$

3.2.2. Ratio of service facility capacity to traffic volume.
The ratio of service facility capacity and traffic volume is an evaluation index to consider whether passengers can smoothly complete the transfer under the restriction of service facility capacity. The calculation formula is as follows:

$$S_y = \frac{Q_y}{\sum \theta_s C_s} \quad (2)$$

3.2.3. Ratio of waiting time to transfer process time.
The ratio of waiting time to transfer process time is an important index reflecting transfer connection and transfer efficiency, and its calculation formula is as follows:
\[
T_e = \frac{T_n}{T_n + T_r}
\]  

(3)

### 3.3. Evaluation model based on EWM-TOPSIS

Common evaluation methods include fuzzy comprehensive evaluation method, AHP, grey correlation method, etc. The calculation of these methods is relatively complex, or the weight of the indicators has a great subjectivity, but there is no obvious correlation between several indicators reflecting the transfer connection ability. So it is necessary to select a method which can not only reflect the order of data information itself, but also reduce the deviation of subjective factors.

Entropy is a measure of the degree of system disorder. The basic idea of EWM (the entropy weight method) is to determine the objective weight according to the degree of index variability. Generally speaking, if the information entropy of an index is smaller, it indicates that the greater the degree of variation of the index value, the more information it provides, the greater the role it can play in the comprehensive evaluation, and the greater the weight. On the contrary, the greater the information entropy of an index is, It shows that the smaller the variation degree of index value, the less information provided, and the smaller the role played in the comprehensive evaluation. Therefore, the weight of each index can be calculated by using information entropy, which provides a basis for the comprehensive evaluation of multiple indexes.

TOPSIS is an effective multi index evaluation method. By constructing positive ideal solution and negative ideal solution of the evaluation problem, TOPSIS can find the best solution and the worst solution of each index, and then calculate the closeness degree from each scheme to the ideal scheme, that is, the degree close to the positive ideal solution and far away from the negative ideal solution, so as to evaluate each scheme. The positive and negative ideal solutions are not true. The existing scheme is the best scheme based on the best value of each index. TOPSIS method has been widely used in the field of transportation, such as service level evaluation.

To sum up, this paper uses EWM-TOPSIS method to evaluate the transfer connection ability. Firstly, entropy method is used to determine the weight of the index, and then TOPSIS method is used to comprehensively evaluate the index.

The algorithm steps are as follows:

**Step 1: determine index value and initial matrix**

The indicators are:

\[ x_1, x_2, \ldots, x_i \]

The initial matrix is:

\[
X = (x_{ij})_{m \times n} = \begin{pmatrix}
  x_{i1} & \cdots & x_{i\ell} \\
  \vdots & \ddots & \vdots \\
  x_{i\ell} & \cdots & x_{im}
\end{pmatrix}
\]

(5)

Here i, j simply represent the growth of number.

**Step 2: matrix standardization**

Standardize the data of each indicator, and the values in the index value table are transformed to [0, 1] interval to eliminate the influence of different dimensions on the evaluation results.

The standardized treatment formula of benefit index is as follows:

\[
y_{ij} = \frac{x_{ij} - \min(x_i)}{\max(x_i) - \min(x_i)}
\]

(6)

The standardized processing formula of cost index is as follows:

\[
y_{ij} = \frac{\max(x_i) - x_{ij}}{\max(x_i) - \min(x_i)}
\]

(7)

The standardized matrix is:

\[
Y = (y_{ij})_{m \times n} = \begin{pmatrix}
  y_{11} & \cdots & y_{1\ell} \\
  \vdots & \ddots & \vdots \\
  y_{\ell1} & \cdots & y_{mn}
\end{pmatrix}
\]

(8)

**Step 3: determine the entropy weight of indicators**
Step 3.1: frequency

\[ p_{ij} = \frac{y_{ij}}{n} \quad (9) \]

Step 3.2: finding information entropy

Let the information entropy of each index be:

\[ E_1, E_2, \ldots, E_i \quad (10) \]

The calculation formula of information entropy is:

\[ E_i = -\ln(n) \sum_{j=1}^{n} p_{ij} \ln p_{ij} \quad (11) \]

Step 3.3: determine the weight of each indicator

Set the weight value of each index as:

\[ W_1, W_2, \ldots, W_j \quad (12) \]

The weight calculation formula is:

\[ W_j = \frac{1 - E_i}{k \sum_{j=1}^{i} E_i} \quad (13) \]

Step 4: determine the weighting matrix

\[ R = \{r_{ij}\}_{mn \times n} = \{w_{ij}y_{ij}\}_{mn \times n} \quad (14) \]

Step 5: determine positive and negative ideal solutions and Euclidean distances

The positive ideal solutions of each index are as follows:

\[ V_j^+ = \max_{i \in \mathbb{J}} r_{ij} \quad (15) \]

The negative ideal solutions of each index are as follows:

\[ V_j^- = \min_{i \in \mathbb{J}} r_{ij} \quad (16) \]

The distance between positive and negative ideal solution and index in each period is as follows:

\[ d_j^+ = \sqrt{\sum_{i=1}^{n} (V_j^+ - r_{ij})^2} \quad (17) \]

\[ d_j^- = \sqrt{\sum_{i=1}^{n} (V_j^- - r_{ij})^2} \quad (18) \]

Step 6: Assessment of terminal transfer and connection capacity

The value range of terminal transfer connection capacity in each period is \([0, 1]\). The larger the connection capacity is, the higher the comprehensive level of terminal transfer in this period is. Based on this, it evaluates the transfer situation of rail transit terminal, as shown in Table II.

\[ Z_j = \frac{d_j^-}{d_j^+ + d_j^-} \quad (19) \]

**TABLE II. EVALUATION CRITERIA FOR TRANSFER AND CONNECTION CAPACITY**

| Grade | A     | B     | C     | D     | E     | F     |
|-------|-------|-------|-------|-------|-------|-------|
| Evaluation | Excellent | Good | Fine | Common | Poor | Bad |
| Value | 0.83-1.00 | 0.67-0.83 | 0.50-0.67 | 0.33-0.50 | 0.17-0.33 | 0.00-0.17 |

4. EXAMPLE ANALYSIS

This paper uses the train timetable and passenger flow data of Chengdu East Railway Station on October 8, 2017. Specifically taking the arrival passenger flow of high-speed, intercity and other railways to transfer to Metro Line 2 and line 7 as an example to verify the feasibility of the model.
4.1. Calculation of Evaluation Index

4.1.1. Ratio of transfer train transportation capacity to traffic volume.
According to the arrival passenger flow and transfer proportion of the railway train, calculate the transfer passenger flow, combined with the operation interval and train transportation capacity of the metro, calculate the ratio between the transportation capacity and the traffic volume of the transfer train of Chengdu East Railway Station in a certain period of time and draw Figure 4 (a). It can be seen that after 19:00, although it is the peak of the railway passenger flow, it is the low peak of the departure interval time of the subway, resulting in the contradiction between a large number of agglomeration of the arrival passenger flow in a short period of time and the limited available transportation capacity of the subway train, so there is a sudden increase phenomenon, and in the morning and evening peak, the decrease of the departure interval time of the subway makes the contradiction relieved.

4.1.2. Ratio of service facility capacity to traffic volume.
According to the scale and capacity of service facilities in each transfer link, passenger flow and selection proportion of service facilities in each link, it can concluded the ratio of service facility capacity to traffic volume, and draw Figure 4 (b). It can be seen that Metro Line 2 and line 7 have facilities sharing service links, and the overall trend of their service facilities capacity is basically consistent with the arrival passenger flow.

4.1.3. Ratio of waiting time to transfer process time.
According to the calculation of passenger flow and facility capacity, the average transfer process time of each period of railway transfer to Metro Line 2 and line 7 is obtained. Combined with the departure interval time of metro trains, considering the type of the index, it calculates the ratio of waiting time and transfer process time of line 2 and line 7 after standardization, and draw Figure 4 (c).

The ratio is mainly distributed between 0.65 and 0.85, which is relatively stable and gentle. The curve has stops at the time when the passenger flow is dense and at the peak of morning and evening. Although the arrival passenger flow in some time periods is not large, the number of arriving trains is small, which will result in a large number of passengers gathering in a short time after the arrival of the train, leading to the accumulation and extension of the transfer process time. In the morning and evening peak, the departure interval is shorter, the average waiting time of passengers is shorter, and the evacuation can be faster.

a. Ratio of transport capacity to volume.

b. Ratio of service facility capacity to traffic volume.
c. Ratio of waiting time to transfer time.

Figure 4. Hourly distribution of each evaluation index.

4.2. Evaluation of Terminal Transfer Connection Capacity

Three indexes are calculated, and then the weight of each index is calculated by entropy weight method, as shown in Table III. Finally, TOPSIS method is used to calculate the terminal transfer connection capacity in the case of railway transfer to Metro in Chengdu east railway station, and Figure 5 is drawn.

| Index weight          | Index 1 | Index 2 | Index 3 |
|-----------------------|---------|---------|---------|
| Metro Line 2 up       | 0.43    | 0.25    | 0.32    |
| Metro Line 2 down     | 0.31    | 0.24    | 0.45    |
| Metro Line 7 up       | 0.26    | 0.19    | 0.55    |
| Metro Line 7 down     | 0.21    | 0.16    | 0.63    |

Figure 5. Hourly distribution of transfer capacity.

It can be seen from the figure that the overall distribution of the transfer capacity curve of the railway transfer and Metro comprehensive terminal is between 0.25 and 0.75. In combination with the distribution of the number of trains arriving at Chengdu east railway station and the hourly passenger flow on a certain day, the arrival passenger flow increases between 12:00-15:00 and 19:00-21:00, and the transfer capacity is stable and relatively high, which is maintained between 0.45-0.75, with good effect. In combination with the average departure interval time of metro, it can be seen that in the morning and evening peak time, the departure interval time of metro train is short. The available transportation capacity is significantly improved, and the transfer and connection capacity fluctuates, and it is relatively low, about 0.25-0.45, with poor effect, which can be improved by changing the departure interval time of Metro in the morning and evening peak period.
5. CONCLUSION
This paper puts forward the ideas and methods of the evaluation of the transfer and connection capacity of the rail transit terminal. Based on the analysis of the whole transfer process in the terminal, the ratio of transfer train transportation capacity and traffic volume, service facility capacity and traffic volume, waiting time and transfer process time are selected as three calculation indexes, and based on EWM-TOPSIS, it establishes the evaluation model of transfer and connection capacity of rail transit terminal. Finally, it analyzes the case of Chengdu east railway station transferring to subway. The case study shows that the transfer capacity is stable and high in general, and in the morning and evening, there will be fluctuation and low. It can be improved by changing the departure interval in the morning and evening rush hours. The case study shows that the evaluation method proposed in this paper is feasible and practical, and the calculation results are relatively accurate and practical. The operability of this model for the calculation of the transfer capacity of other transfer modes needs to be further tested. At the same time, in the evaluation of transfer connection ability, the determination of weight and scientific evaluation methods have a great impact on the evaluation results. Therefore, it is the next step to explore the relationship between various indicators and establish a more objective and accurate calculation model of weight and ability.

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