Evaluation Research of Passenger Flow Organizational Schemes in Metro Transfer Station

Guoxing Han, Yong Qin, Jie Xu, Ping Liang, and Yu Liu

***Abstract*—The passenger flow organizational schemes have directly impact on the operational efficiency and order of metro transfer stations. Firstly, the new but reasonable index system of the passenger flow organizational schemes is provided, which involves the aspects of transfer time, distance, detour distance, transfer volume, etc. Then, the corresponding quantified method of each index is come up with to handle the investigative data. Finally, based on the multi-layer fuzzy comprehensive evaluation method, we evaluate the organizational schemes of Beitucheng transfer station in Beijing Subway, aiming to differentiate the scale of each scheme as well as the priority selection for passengers.**

***Index Terms*—Metro transfer station, passenger flow organizational scheme, multi-layer fuzzy comprehensive evaluation, priority selection.**

I. Introduction

Extremely expanding as the urban transport network is, metro transfer stations are playing more significant roles. It directly affects the operation efficiency and order of metro transfer station whether the passenger flow organizational schemes are efficient or not. However, there doesn't exist some reasonable evaluation indexes for the transfer schemes. Therefore, some further research should be urgently done to improve the transfer organizational efficiency.

Better measures of passenger organization was proposed in [1] based on the characteristics of passenger f low in the transfer stat ion and considered constitution and distribution of passenger organization. Song and Zheng [2] did some research on the transfer mode and the combination of platform considering the passenger influence, then gave the reasonable mode to interchange and reduce the transfer times, which is proved to improve the transfer efficiency greatly. In addition, Yang and Xu [3] simulated the key problems of large-scale pedestrian organization at urban rail transfer station under the background of Shanghai World Expo, finally proposed some improvements to the optimization and station facilities as well as some suggestions to guide rational distribution of station staff. All these previous works ([4-5], included) that analyzed the passenger flow organization problems are lack of the actual analysis to the passenger flow data during the rush hours, which maybe can't match the actual situation. Although some evaluation indexes were proposed to evaluate the transfer station, they are not suitable the evaluation of passenger flow organization of transfer station during rush hours, however, the evaluation of passenger flow organization is crucial to be done. Therefore, this paper establishes the evaluation index system and the corresponding quantified method that are suitable to the evaluation of passenger flow organization. The establishment and method is based on the actual situation of transfer station during rush hours. Multi-layer fuzzy comprehensive evaluation method is presented to evaluate the schemes.

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II. The Evaluation Index System of Passenger Flow Organizational Schemes

Metro transfer stations act the important role of passenger flow collection and distribution during rush hours. The passengers who are in the transfer station need to transfer from one line to another as soon as possible so that they won't be late for work. And at the same time, getting rid of unexpected situation is the inner expectation and the service they deserve as well as a comfortable environment. Therefore, in order to insure the transfer efficiency, the transfer schemes should not only be high performance and convenient, also be safe and comfortable. The paper establishes the evaluation index system of passenger flow organizational schemes (Fig.1) according to the principle of "entirety, hierarchy, independence, measurability", and takes the main factors above into consideration at the same time.

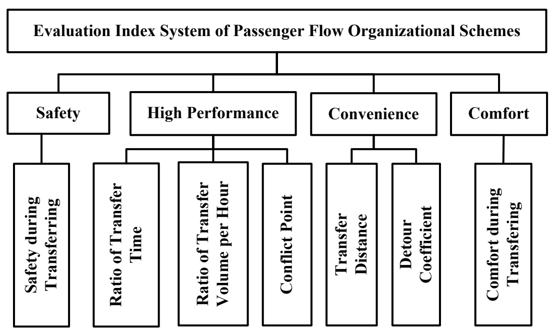

Fig. 1. Evaluation index system of passenger flow organizational scheme

The indexes of each layer are explaining and quantified as bellows:

A. Ratio of Transfer Time

On Feb. 27th 2012, "Urban Rail Transit Engineering Design Standard (Opinion Soliciting Draft)[6]"was proposed as the new standard of metro construction in Beijing, which specifies that the transfer time of one-platform-interchange should be less than 1 minute, 3 and 5 minutes of transfer time at node and channel respectively.

Let τ_{AB}^{i} denote the ratio of transfer time of the *i*-th scheme between line A and line B. And t_{AB}^{i} denote the corresponding transfer time. t_0 stands for the max standard transfer time, which equals to 1 or 3 according to the standard above. Then we define the transfer time ratio τ_{AB}^{i} with the following formula:

$$\tau_{AB}^{i} = t_{AB}^{i} / t_0 \tag{1}$$

τ_{AB}^{i} is a negative index, it means that the higher the value is, the transfer time consumed is more, the corresponding scheme is worst.

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B. Ratio of Transfer Volume Per Hour

Let Q_{AB}^{i} denote the transfer volume of the *i*-th scheme between line A and line B during the time *t*, then the transfer volume per hour $\bar{Q}_{AB}^{i}$ can derive from the formula (2):

$$\bar{Q}_{AB}^{i} = Q_{AB}^{i}(t) / t \tag{2}$$

We define the ratio of transfer volume per hour as below: If there are *c* schemes between line A and line B, and c_k of them derive from the same transfer channel or facility, with the corresponding transfer volume per hour of $\bar{Q}_{AB}^{i}\ (i = 1, 2, ..., k)$, so we have the ratio of transfer volume per hour α_{AB}^{i} :

$$\alpha_{AB}^{i} = \bar{Q}_{AB}^{i} \Big/ \sum_{i=1}^{k} \bar{Q}_{AB}^{i}, (i = 1, 2, ..., k) \tag{3}$$

We analogically assume the ratio the best when between 75-85 percent with reference to [7], because the ratio is unreasonable if it is more or less than that. When the ratio is tending to 1 or 0, it means nearly all the passengers assemble at the same scheme, which may cause potential danger.

C. Numbers of Conflict Points

With reference to the concepts of conflict point in road traffic, define: If every two routes of passenger flow can't converge, when passengers take the route p_{ij} from origin O_i to destination D_j and take the route p_{mn} from origin O_m to destination D_n, we consider the intersection of the two route a conflict point. General speaking, the less conflict point a scheme has, the better.

D. Transfer Distance

We have the same definition of transfer distance with the general urban rail transfer station [7]: Let *H* denote the horizontal distance of the two transfer stations, *V* denote the vertical distance, so we have the transfer distance *D* from (4):

$$D = H + k \bullet V \tag{4}$$

where *k* is the coefficient of distance increasing up/down stairs .when going up stairs , *k*=4.0; *k*=2.0 for down stairs and 1.0 for elevators.

Due to the actual situation of each transfer station, the distance varies a lot. Therefore, the ranges of evaluation scale of transfer distance need treat differently.

E. Detour Coefficient

Let D_{AB}^{i} denote the actual transfer distance *i*-th scheme between line A and line B, *c* denote the total number of the transfer schemes. So the detour coefficient χ_{AB}^{i} is defined as the ratio between D_{AB}^{i} and the average transfer distance:

$$\chi_{AB}^{i} = D_{AB}^{i} \Big/ \left(\frac{1}{c} \bullet \sum_{i=1}^{c} D_{AB}^{i} \right) \tag{5}$$

Detour coefficient is also a negative index, which means that the higher value of the detour coefficient is, the actual transfer distance is farther, and affects the passengers more..

F. Safety during the Transfer Process

This is a quite complex index, which involves many aspects such as safety of the transfer facility and the safe measures to ensure the passengers' safety. But in order to differentiate the sub-evaluation index and come up with a quantified method, we analyze the main factors. The safety during transfer, to a large extent, affects the passengers' satisfaction towards the passenger flow organizational schemes at the station. This is a qualitative index, and we classify the scales by scoring.

G. Comforts during the Transfer Proces

When transferring in the transfer station, few passengers would dwell at one place for a long time, so the evaluation of comfort mainly takes feeling caused by the facility that passengers use during the process into consideration, including the vertical height of the stairs, elevators or not. As we all know, when going up or down stairs and whether there are elevators, we have the different feelings. Therefore, we take the number of stair steps and elevators or not as the quantified factor [9].

With careful analysis and reference to the definition of transfer distance, we come up with the following function between comfort and height of stairs, horizontal distance, vertical height and the elevator using or not:

$$\varphi_{ij} = (40\%a + 60\%c)V_{ij}^{up} + bH + (40\%d + 60\%c)V_{ij}^{down} \tag{6}$$

In formula (6), φ_{ij} represents for the comfort during the transfer process, $V_{ij}^{up}, V_{ij}^{down}$ represents the vertical height of up or down stairs respectively, *H* is the horizontal transfer distance. The percentage of 40 and 60 means the probability of passengers who choose the stairs and elevators in rush hours (here we use the compromise value) [8].In addition, a, b, c, d is the coefficient of transfer comfort, with the value determined in Table I.

TABLE I. THE MEANING AND VALUE OF THE COMFORT COEFFICIENT

Coefficient	a	b	c	d
Meaning	Up	Horizontally	Elevator	Down
Value	4	1.5	1	2

III. Evaluation Analysis of Passenger Flow Organizational Schemes

To demonstrate the index system and evaluate the organizational schemes, a transfer station of Beijing Subway — Beitucheng Station, is chosen for case analysis. Beitucheng is a station that connects line 8 and 10, the layout structure is shown in Fig. 2, in which ⓘ (i=1,2,…,23) represent the facility that passengers pass through.

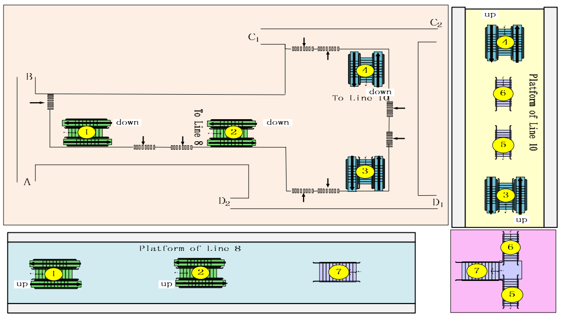

Fig. 2. The layout structure of Beitucheng transfer station

Here we mainly talk about the transfer passengers in the station because quite a large number of the passengers accomplish the transfer process rather than in or out of the station. When passengers transfer, the schemes mainly come from the following choices, showed in Table II:

TABLE II: The Schemes of Passenger Flow Organizational Schemes

Transfer Direction	Line 8→Line 10	Line 10→Line 8
Transfer Scheme	Ⅰ*：①→④	Ⅴ：⑥→⑦
	Ⅱ：①→③	Ⅴ：⑤→⑦
	Ⅲ：②→④	Ⅵ：③→②
	Ⅳ：②→③	Ⅶ：④→②

*In Table II, the order number Ⅰ ～Ⅶ represent the *i*-th scheme, and we regard the scheme ⑥→⑦and⑤→⑦ as the same scheme and number the order Ⅴ.

A. Evaluation Indexes Scale Ranges of Passenger Flow Organizational Schemes

According to the analysis and quantified method of all the indexes and the investigative data (shown in appendix 1), we can derive the scale and corresponding value ranges in Table III. In the table, u_i (i=1,2,…,7) represents the corresponding index respectively in 2.1 to 2.7. And all of these ranges are suggested in relation with their properties and actual value of the certain station.

TABLE III: The Scale and Evaluation Value Range of the Indexes

Scale	A	B	C	D	E
Value	1～0.9	0.9～0.75	0.75～0.6	0.6～0.4	0.4～0
u_1	≤0.2	0.2～0.4	0.4～0.6	0.6～0.8	≥0.8
u_2	0.75～ 0.85	0.6～0.75 0.85～0.9	0.45～0.6 0.9～0.94	0.3～0.45 0.94～ 0.98	0～0.3 0.98～1
u_3	≤2	3-4	5-6	7-9	≥10
u_4	≤50	50～100	100～150	150～200	≥200
u_5	≤0.8	0.8～1.2	1.2～1.6	1.6～2	≥2
u_6	90～100	75～90	60～75	40～60	≤40
u_7	≤40	40～80	80～120	120～160	160～200

B. Multi-layer Fuzzy Comprehensive Evaluation of Passenger Flow Organizational Schemes

We choose the multi-layer fuzzy comprehensive evaluation method to analyze the organizational schemes in Beitucheng transfer station, based on the former analysis of the involved indexes and the processed data (appendix 2).

Firstly, establish the evaluation set for indexes. The set should be divided into two layers: The first layer is composed of "high performance, convenient, safety and comfort", which is denoted by U_1, U_2, U_3, U_4. The second layer is sub-index set that explicitly illustrates $U_i (i = 1,2,3,4)$, and $U_1 = \{u_1, u_2, u_3\}$ $U_2 = \{u_4, u_5\}$ $U_3 = \{u_6\}$ $U_4 = \{u_7\}$ [10]. Secondly, regard the seven schemes of Beitucheng station as the elements of the evaluation set. Then, differentiate the weight of each index by Delphi, and correct the weight with entropy, seen in Table IV.

TABLE IV: The Weight of Each Indexes

	Evaluation Indexes System						
First Layer	U_1 (0.42)			U_2 (0.35)		U_3 (0.11)	U_4 (0.12)
Second Layer	u_1 (0.5)	u_2 (0.35)	u_3 (0.15)	u_4 (0.55)	u_5 (0.45)	u_6 (1.0)	u_7 (1.0)

The indexes value is fuzzed by trapezoidal fuzzy membership functions, and the fuzzier data is shown as below:

TABLE V: The Fuzzy Membership Value of Each Index

Transfer Direction	Line 8→Line 10				Line 10→Line 8		
Scheme	Ⅰ	Ⅱ	Ⅲ	Ⅳ	Ⅴ	Ⅵ	Ⅶ
u_1	0.8125	0.8	0.5	0.4625	0.2	0.4	0.425
u_2	0.6875	0.125	0.85	0.7375	0.9375	0.075	0.0875
u_3	0.5	0.4	0.5	0.6	1	0.6	0.5
u_4	0.3687	0.3207	0.5142	0.5337	0.977	0.7274	0.7079
u_5	0.6875	0.6438	0.825	0.8438	1	0.325	0.2688
u_6	0.73	0.66	0.78	0.84	0.94	0.72	0.77
u_7	0.5045	0.4325	0.7228	0.7521	1	0.7905	0.7612

To avoid the failure of the multi-layer fuzzy comprehensive method because of the operator, we operate the matrix with $M(\bullet, \vee)$ represented by "$\circ$", so let W_U^i denote the weight of $U_i (i = 1,2,3,4)$, and w_j denote the weight of $u_j (j = 1,2,..,7)$, $B_i (i = 1,2,3,4)$ denote the fuzzy relationship matrix of the second layer, .we have:

$$A = \begin{bmatrix} W_U^1 \circ [(w_1, w_2, w_3) \circ B_1] \\ W_U^2 \circ [(w_4, w_5) \circ B_2] \\ W_U^3 \circ [(w_6) \circ B_3] \\ W_U^4 \circ [(w_7) \circ B_4] \end{bmatrix} \quad (7)$$

Here,

$$B_1 = \begin{pmatrix} 0.8125 & 0.8 & 0.5 & 0.4625 & 0.2 & 0.4 & 0.425 \\ 0.6875 & 0.125 & 0.85 & 0.7375 & 0.9375 & 0.075 & 0.0875 \\ 0.5 & 0.4 & 0.5 & 0.6 & 1 & 0.6 & 0.5 \end{pmatrix}$$

$$B_2 = \begin{pmatrix} 0.3687 & 0.3207 & 0.5142 & 0.5337 & 0.977 & 0.7274 & 0.7079 \\ 0.6875 & 0.6438 & 0.825 & 0.8438 & 1 & 0.325 & 0.2688 \end{pmatrix}$$

$$B_3 = (0.73 \ \ 0.66 \ \ 0.78 \ \ 0.84 \ \ 0.94 \ \ 0.72 \ \ 0.77)$$

$B_4 = (0.5045 \ \ 0.4325 \ \ 0.7228 \ \ 0.7521 \ \ 1 \ \ 0.7905 \ \ 0.7612)$

According to the results of formula (7), we have the final evaluation result:

$A = (0.6233 \ \ 0.4992 \ \ 0.6629 \ \ 0.6616 \ \ 0.8118 \ \ 0.4981 \ \ 0.4883)$

Refer to Table III, we can differentiate the scale of each passenger flow organizational scheme. The score of scheme Ⅴ is 0.8118, falling in the scale B, so the scheme Ⅴ is Scale B, the others are analyzed analogically. Finally, we get the evaluation result in Table VI.

TABLE Ⅵ: THE EVALUATE RESULTS OF THE TRANSFER SCHEMES

Direction	Line 8→Line 10				Line 10→Line 8		
Scheme	Ⅰ	Ⅱ	Ⅲ	Ⅳ	Ⅴ	Ⅵ	Ⅶ
Result	0.6233	0.4992	0.6629	0.6616	0.8118	0.4981	0.4883
Scale	C	D	C	C	B	D	D

Although the scheme of Ⅰ,Ⅲ,Ⅳand Ⅱ,Ⅵ,Ⅶ are in the same scale of "C" and "D" respectively (Fig.3), the evaluation values vary a lot. Therefore, there are some priority selections among them. When passengers decide which the best transfer scheme to choose currently is, the evaluation would give the answer. Comparing the evaluation values of table 6, we have the conclusion: when transferring from line 8 to 10, scheme Ⅲ ≻ Ⅳ ≻ Ⅰ ≻ Ⅱ;In adverse, when line 10 to 8, Ⅴ ≻ Ⅵ ≻ Ⅶ, where "≻" is a symbol that means "superior to" or "better than".

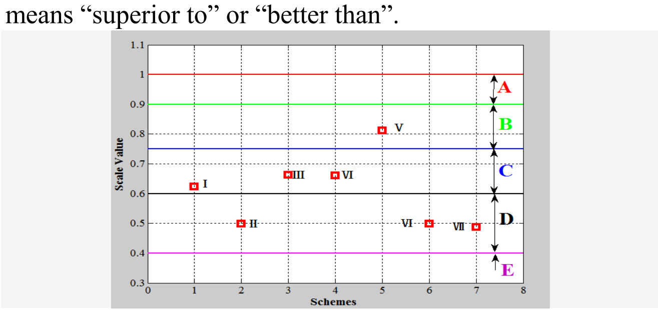

Fig. 3. The graphic illustration of the evaluation result

IV. CONCLUSIONS

The paper mainly focuses on the evaluation of passenger flow organizational schemes in metro station. New evaluation indexes and quantified methods which are reasonable and measurable in the evaluation of passenger flow organizational schemes are proposed. At the end of the paper, we exemplify the metro transfer station—Beitucheng of Beijing Subway, and based on the multi-comprehensive method, demonstrate the evaluation index system and evaluate seven schemes when passengers transfer. In addition, we come up with the priority selection of the scheme of the same scale in view of the evaluation results, aiming to improve the transfer efficiency of passengers.

Of course, the result of the evaluation can be also utilized by the operation department to optimize transfer organization.

APPENDIX

The investigative data of the current scheme values in Beitucheng transfer station of Beijing Subway is shown in appendix 1,and the reasonable processed data is shown in appendix 2.

APPENDIX Ⅰ: THE INVESTIGATIVE DATA OF BEWITCHING TRANSFER STATION

Direction	Line 8→Line 10				Line 10→Line 8		
Schemes	Ⅰ	Ⅱ	Ⅲ	Ⅳ	Ⅴ	Ⅵ	Ⅶ
Transfer Time[s]	124	123	88	85	18	77	80
Transfer Volume [person per hour]	2694	582	3318	2843	3336	324	359
Conflict Point	5	6	5	4	0	4	5
Transfer Distance[m]	146.26	155.86	117.16	113.26	24.6	74.52	78.42
Detour Coefficient[m]	--*	--	--	--	--	--	--
Safety Scores	73	66	78	84	94	72	77
Comfort Index	--	--	--	--	--	--	--

*:" --" means that the corresponding data cannot be investigated directly.

APPENDIX Ⅱ:THE ANALYZED AND PROCESSED RESULTS OF THE INVESTIGATION DATA

Direction	Line 8→Line 10				Line 10→Line 8		
Scheme	Ⅰ	Ⅱ	Ⅲ	Ⅳ	Ⅴ	Ⅵ	Ⅶ
u_1	0.69	0.68	0.49	0.47	0.30	0.43	0.44
u_2	0.57	0.12	0.70	0.61	0.83	0.08	0.09
u_3	5	6	5	4	0	4	5
u_4	146.26	155.86	117.16	113.26	24.6	74.52	78.42
u_5	1.1	1.17	0.88	0.85	0.55	1.68	1.77
u_6	73	66	78	84	94	72	77
u_7	129.09	143.49	85.44	79.59	27.44	71.9	77.75

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