A facilities state-based evaluation method on level of service in subway station

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Abstract

Subway station is the key node in the urban rail transit system. Its level of service affects directly the subway's operation efficiency and traveller's choice of track traffic way to travel. Considering the facility characteristics in subway station and pedestrians perspective, on the basis of a large number of survey data, this paper identifies the facilities which impact the level of service in subway station mainly, takes safety, comfort and smoothness as evaluation index, and evaluates respectively from the entrance, channel and platform area. The judgment matrix of facilities condition influence in each region on pedestrians is constructed and the evaluation model of level of service in subway station has been built based on the facility state. Finally taking PingGuoYuan subway station as instance for analysis, the result verifies that the evaluation method is effective.

Keywords: urban transportation, facilities state, level of service, judgment matrix, pedestrian experience

1 Introduction

Subway has been chosen as the main daily traffic trip with more and more cities starting to build. Thus, it becomes a priority in rail transit to make sure the LOS (level of service) of subway station, which depends on good, reasonable and effective running of facilities in subway station. Accurate evaluation of the LOS could promote the operational efficiency, make passengers safety and provide guidance for equipment maintenance in subway station.

There are many researches on LOS of subway station. Gong X Land Li D P et al studied the LOS of a particular area in subway station. Cao S H and Liu P X et al put forward a method for evaluating LOS, which puts people first. Wang B et al came up with a method to evaluate the LOS of a certain kind of facility in subway station. Many researches on LOS of subway station mainly depend on questionnaire and simulation. M Mori et al put forward a way to evaluate the LOS which depends on advices and behaviours of pedestrian. F Kaakai et al evaluated the LOS through simulation on facilities. There are also some people taking satisfaction of travellers to evaluate the LOS (SA, Lei, 2010). Based on our study of present researches, there are few researches, which take consideration of both passengers' feelings and station facilities.

The LOS of subway station depends on many factors, which result from the interaction of passengers and facilities. Based on existing research results, this paper considers both passengers' feelings and facility characteristics. On basis of the influence of facility on flow density, the main factors which influence LOS of subway station including passengers' feelings, safety, comfort and smoothness are proposed, and the method to evaluate the LOS of subway station which based on facility state is put forward.

2 Data Collection

2.1 INVESTGATION CONTENT

PingGuoYuan subway station, which is the terminal station of Line 1 in Beijing, has apparent traffic tide phenomenon with large passenger flow. We investigated its facility configuration, facility service capability and its aisle access space. The site investigation content is showed in Table 1.

TABLE 1 Investigation content

Survey area	Investigation content
Entrance area	Number of ticket machine
	Queuing length of pedestrians
	Available walking area in access area
	Queuing length on front of safety check (Period of time statistics, flat and peak)
	Number of automatic gate machine, check time at flat and peak(count the number of people in 15 minutes)
Passage area	Stairs: step height, step length, the max delivery capacity
	Record the number of checked people per unit time
Platform area	Platform area(length, width), available queuing area, queuing length in 15 minutes at flat and peak(select few platform random)
	Record the number of people who has arrived platform from passage (15 minutes).

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At the same time, an online questionnaire, covering the age and status of pedestrians, the important degree of auxiliary device, the influence of service facility, the choose wishes and satisfaction of pedestrians and frequency of auxiliary device, is conducted. The degree of importance of facility in this questionnaire has three levels, which is unimportant, general and very important.

2.2 INVESTGATION RESULT

Through the investigation, we can get that the standard equipment configuration in subway station include automatic ticket vending machine, automatic gate machine, security equipment, information display screen, self-service terminals, elevator/escalator, oriented facilities and assistance call. PingGuoYuan subway station has these characteristics: two entrances, outdoor artificial ticket booth, limited flow facility in entry, security equipment, six automatic gate machines in every entrance, and 24 queuing area in platform area.

In this survey, 100 valid questionnaires are taken for study. The proportion of age among the respondents is 1.47% under 18 years old, 80.88% between 18 and 25 years old, 17.65% between 26 and 55 years old. Nobody is above 55 years old. The occupations of respondents include students, office workers and freelancers. There are 47.06% student, 48.53% office workers and 4.41% freelancers. After analysis the collecting data, the factors influencing the LOS of subway station are passengers' age and identity, security equipment, automatic gate machine, automatic ticket vending machine, elevator/escalator, self-service terminals, oriented facilities and assistance call.

3 LOS index system of subway station

3.1 DATA ANALYSIS

The factors which can influence the LOS of subway station fall into three types: behavioural characteristics, traffic efficiency and equipment completeness. The weight of different equipment on LOS and the weight of passengers' age and identity was obtained through YaAHP, which is a software using AHP Method. All of the factors weight is shown in Table 2. The weight in Table 2 was just a reference to judge the main facilities influencing the LOS of subway station because the data is get according to people's subjective feeling. Combining the properties of impact of facilities on pedestrians with Table 2, the main facilities influencing the LOS are automatic gate machine, security equipment and elevator/escalator. The stair is a non-electric device, so it did not been involved though it has big effect on traffic efficiency and travel time. It only involves age and identity on respondent in this survey, so the weight of age and status in Table 2 are the same as the weight of the passengers' feeling. Self-service terminals and assistance call are excluded as secondary cause for their low weight.

The index, which can influence the LOS, is confirmed by the characters of main factors including safety, comfort and smoothness.

TABLE 2 Influence factors weight

Influence factor	Weight
identity	0.0714
age	0.0714
security equipment	0.2834
automatic gate machine	0.2834
automatic ticket vending machine	0.0644
elevator/escalator	0.0831
information display screen	0.0356
self-service terminals	0.0138
oriented facilities	0.0797
assistance call	0.0138

3.2 DETERMINATION OF EVALUATION INDEX

Passengers are the service clients of facilities in subway station and they are with perceptual. Therefore, passengers' feeling is one of the factors affecting the LOS. The existing research (Lu C X, 2006) shows that crowded accident would not happen when the flow density is low and pedestrians walk freely. When the flow density reaches a critical point, the interaction of speed and density will lead to a crowded accident. There is a direct relationship between comfort level and pedestrian density. The pedestrian walking speed slows down and will feel uncomfortable as the pedestrian density increases. Meanwhile the safety, comfort and smoothness will get lower. Therefore, this paper will evaluate the safety, comfort and smoothness with the pedestrian density as the core.

The interaction among pedestrians brings crowded feeling and either does the interaction between facilities and pedestrians. The crowded will increase when some facility does not work well. Since the degree of congestion in subway station has different feature in different area, this paper divides the transfer area into three parts for study, including entrance, passage and platform. There are security equipment, automatic gate machine and ticketing equipment in entrance, where has relatively concentrated crow flow and will produce queues. Elevator, escalator and stairs are in passage, which has the characteristics of uniform flow density and speed. The platform area's main characteristics are scattered distribution of crow flow and most of the crow flow distributed in entrance area of the train.

(1) Safety: this paper use U_1 to show the safety degree of facility. It represents the ratio of crowd flow in the area to the max crowd flow it can bear (Ran L J, Liu M, 2007). U_1 is calculated using Equation 1 below.

$$U_1 = 1 - \frac{p}{p_{max}}, \tag{1}$$

where p is crowd flow in the area and p_{max} is the max

crowd flow it can bear.

(2) Comfort: this paper use U_2 to show the degree of comfort, that is the passengers' feeling about the subway station service. It is the ratio of average flow density in the area to the max crowd flow, which people can endure.

$$U_2 = 1 - \frac{k}{k_{max}}, \tag{2}$$

where k is average flow density of the facility, k_{max} is the max flow density people can bear.

(3) Smoothness: U_3 was used to show the level of smoothness. The measure method is using the ratio of average delay time of getting through the area to the average time of transfer in the subway station. U_3 is calculated according to the following formula.

$$U_3 = 1 - \frac{t}{T}, \tag{3}$$

where t is average delay time of pedestrians at peak and the T is average time of passing the subway station.

4 Comprehensive LOS evaluation of subway station

4.1 ESTABLISHING THE HIERARCHY STRUCTURE OF EVALUATION

The LOS of subway station is evaluated by these factors including comfort level, safety and smoothness of pedestrians in subway station. The safety, comfort and smoothness will be evaluated in three areas and can be estimated by the configuration of facilities and the influence of facilities on people in each region. Figure 1 shows the evaluation structure of LOS.
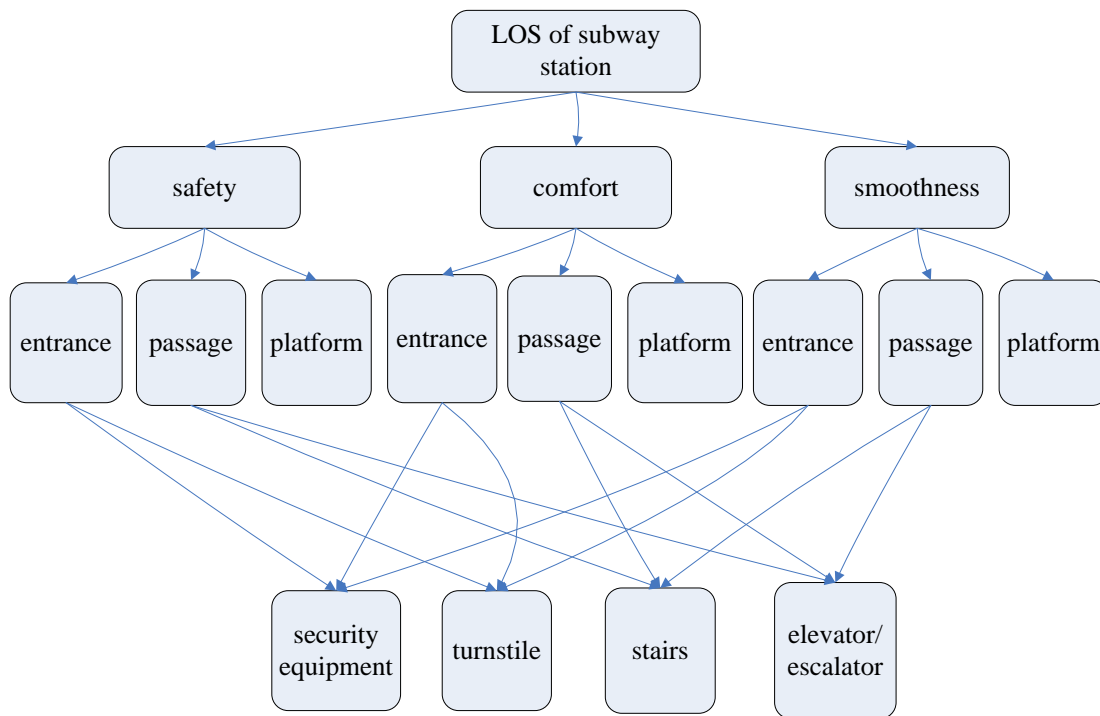

FIGURE 1 Hierarchy structure of evaluation

4.2 BUILDING THE JUDGMENT MATRIX

For requiring the influence weight of each region, the AHP method is used to analyse the impact of the facilities in each region on safety, comfort and smoothness according to 1-9 degree calibration method and get the judgment matrix.

(1) The basis of judging the influence weight of facilities on safety in each region. As the definition of safety, the region safety is related to passenger flow and the possible accident when the passenger flow exceeds the carrying capacity of service facility. So the weight of each facility can be judged by the transport capacity of the facility, and the transfer capacity will go down when

the facility does not work. The declining degree of safety caused by the change of operating status of each facility can be calculated by the following formula.

$$\Delta U_1 = \left(1 - \frac{S\rho_0}{P_{max}}\right) - \left(1 - \frac{\rho_1}{P_{max}}\right), \tag{4}$$

where ρ_0 is the average flow density when the facilities in this area is good. ρ_1 is the average flow density when the facilities' operating status changed. P_{max} is the standard flow density of safety in China which is 9 per/m². The influence weight of each facility on region safety can

be got by comparing ΔU_1 of each facility. The influence weight of each region safety on the safety of subway station can be measured by hidden danger and the flow density of each region.

(2) The basis of judging the influence weight of facilities on comfort in each region. Region comfort is related with average passenger flow in the area, which would increase when the facility does not work well. Therefore, the weight of each facility can be judged by the facility influence on average flow density. The declining degree of comfort caused by the change of operating status of each facility can be calculated by the following formula.

$$\Delta U_2 = \left(1 - \frac{k_0}{k_{max}}\right) - \left(1 - \frac{k_1}{k_{max}}\right), \qquad (5)$$

where k_0 is the average flow density when facilities in the area are available. k_{max} is the max flow density people can bear which can be get by questionnaire. k_1 is the average flow density when the status of facility changes. Here k_0 is the same as ρ_0 and k_1 is the same as ρ_1 in formula (4). The influence weight of each region on the comfort of subway station can be measured by the duration of crowded.

(3) The basis of judging the influence weight of facilities on smoothness in each region. Region smoothness is related to average delay time. The weight of each facility can be judged by the facility efficiency. The crowded will get worse once the operating status of facility gets bad. That is to say, the flow density will increase, the pedestrian speed will slow down, and the average delay time will increase. Hence, the declining degree of smoothness caused by the change of operating status of each facility can be calculated by the following formula.

$$\Delta U_3 = \left(1 - \frac{t_0}{T}\right) - \left(1 - \frac{t_1}{T}\right), \qquad (6)$$

where t_0 is the average delay time at peak when all the facilities is available. t_1 is the average delay time when the operating of facility changes. T is the time of passing the subway station. The influence weight of each region on the smoothness of subway station can be measured by the time of staying in the area.

The weight of safety, comfort and smoothness of each facility can be obtained by 1-9 point calibration and judgment matrix according to the formulas (4), (5) and (6).

Then it is turn to calculate the weight and check the consistency using the software YaAHP, which can simplify the procedure. Importing the judgment matrix directly to YaAHP, and then it will check the consistency

automatically. If the matrix has good consistency, the weight it calculated is the one we need, otherwise the elements in the matrix need be adjusted to until good consistency and the weight should be calculated again.

4.3 EVALUATION MODEL

The service level of subway station can be evaluated by the degree of comfort, safety and smoothness. The comfort of entrance can be calculated as the formula $C_1 = U_{21}(\alpha_1 z_1 + \alpha_2 z_2)$, U_{21} is the comfort of entrance, z_1 is the operating status of security equipment, z_2 is the operating status of automatic gate machine, α_1, α_2 respectively shows the influence weight of security equipment and automatic gate machine on the entrance. The comfort of passage region can be calculated as the formula $C_2 = U_{22}(\alpha_3 z_3 + \alpha_4 z_4)$, U_{22} is the comfort of passage area, z_3, z_4, is the operating status of stair and escalator, α_3, α_4 respectively shows the influence weight of stair and escalator on the passage area. There is no facility which can effect the comfort in platform area, so the comfort of platform is $C_3 = U_{23}$. The influence weight of comfort in entrance, passage and platform on the whole subway station are ω_1, ω_2 and ω_3. The comfort of subway can be calculated as the following formula.

$$C = \omega_1 U_{21}(\alpha_1 z_1 + \alpha_2 z_2) + \omega_2 U_{22}(\alpha_3 z_3 + \alpha_4 z_4) + \omega_3 U_{23}. \quad (7)$$

The safety of subway can be calculated as:

$$S = \alpha_1 U_{11}(s_1 z_1 + s_2 z_2) + \alpha_2 U_{12}(s_3 z_3 + s_4 z_4) + \alpha_3 U_{13}, \qquad (8)$$

α_1, α_2 and α_3 respectively shows the influence weight of entrance, passage and platform on the safety of the subway station. U_{11}, U_{12} and U_{13} respectively shows the safety of entrance, passage and platform. s_1 and s_2 respectively shows the influence weight of security equipment and automatic gate machine on the safety in the entrance area. s_3 and s_4 respectively shows the influence weight of stair and escalator on the safety in the passage area.

Similarly, the degree of smoothness can be calculated as:

$$F = \beta_1 U_{31}(m_1 z_1 + m_2 z_2) + \beta_2 U_{32}(m_3 z_3 + m_4 z_4) + \beta_3 U_{33}. \quad (9)$$

The influence weight of comfort, safety and smoothness on the LOS of subway station respectively is α_2 and α_3, so the LOS of subway station can be calculated as the following formula.

$$L = \alpha_1 C + \alpha_2 S + \alpha_3 F . \qquad (10)$$

The LOS of subway station can be calculated according to the value of L and showed in Table 3.

TABLE 3 Evaluation standard

LOS	Score
A excellent	1.0
B very good	0.9
C good	0.8
D qualified	0.6
E bad	0.4
F very bad	0.2

5 Case study

PingGuoYuan subway station is taken as an example to evaluate the LOS of subway station. We survey this subway station for a whole week and select the peak time 7:00-9:00 as the survey time. The passenger flow and transfer time during the peak time are recorded. Then we establish judgment matrix according to the survey data and use the YaAHP software to get judgment matrix and weight.

(1) The first level judgment matrix and weight

The ratio of matrix consistency is 0.0825, and the general objective weight is 1.0 (Table 4).

TABLE 4 LOS judgment matrix

LOS	Comfort	Safety	Smoothness	Weight
Comfort	1	1/5	1/3	0.1007
Safety	5	1	4	0.6738
Smoothness	3	1/4	1	0.2255

(2) The second level judgment matrix and weight

The ratio of matrix consistency is 0.0000 and the general objective weight is 0.1007 (Table 5)

TABLE 5 Comfort judgment matrix

Comfort	Entrance	Passage	Platform	Weight
Entrance	1	3	3	0.6
Passage	1/3	1	1	0.2
Platform	1/3	1	1	0.2

The ratio of matrix consistency of safety is 0.0236, and the weight to the general objective is 0.6738 (Table 6)

TABLE 6 Safety judgment matrix

Safety	Entrance	Passage	Platform	Weight
Entrance	1	2	1/4	0.1998
Passage	1/2	1	1/5	0.1168
Platform	4	5	1	0.6833

The ratio of matrix consistency of smoothness is 0.0236, and the general objective weight 0.2255 (Table 7)

TABLE 7 Smoothness judgment matrix

Smoothness	Entrance	Passage	Platform	Weight
Entrance	1	4	5	0.6833
Passage	1/5	1	2	0.1998
Platform	1/5	1/2	1	0.1168

According to the influence of security equipment, automatic gate machine, stair and escalator on pedestrians, the influence weight of comfort, safety and smoothness are got in its region respectively. The comfort weight of the equipment to its region is 0.75, 0.25, 0.25, 0.75, the safety weight respectively is 0.83, 0.17, 0.75, 0.25 and the smoothness weight respectively is 0.75, 0.25, 0.25, 0.75.

We use Thursday's data to compare difference of LOS when facilities' status changes, for an automatic gate machine does not work on that day. Because of its stabilized passengers flow, Friday's data is selected to compare with the LOS on Thursday. According to the survey, there are six automatic gate machines in PingGuoYuan subway station; five is good and one does not work on Thursday, all of them are well on Friday. The passengers flow of entrance is 5860 per/h on Thursday and 5560 per/h on Friday.

Suppose z=1 when the facility is well, z=0 when facility's status changes. Then z_1 =5/6=0.83, z_2 =1, z_3 =1, z_4 =0. On the basis of the survey data, the safety at peak time is U_{11} =0.89, U_{12} =0.75, U_{13} =0.78; the comfort is U_{21} =0.8, U_{22} =0.95, U_{23} =0.54, and the degree of smoothness is U_{31}= 0.94, U_{32} =1, U_{33} =1.

The LOS of subway station on Thursday and Friday can be calculated as the formula (7), (8), (9) and (10). The results are showed in Table 8.

TABLE 8 LOS of PingGuoYuan

Thursday	C=0.7168	S=0.773	F=0.877	L=0.79
Friday	C=0.778	S=0.78	F=0.96	L=0.82

Contrast with the Table 3, the LOS of PingGuo Yuan subway station on Thursday is between C and D, the LOS is close to good. The service level of PingGuoYuan subway station on Friday is good. Contrast with it on Thursday, the status of facility can influence the LOS of subway station, and the LOS will decline from good to qualified when an automatic gate machine is bad. The LOS of PingGuoYuan subway station has been evaluated accurately by this method and it corresponds to the actual situation.

6 Conclusion

On the basis of site investigation and online questionnaire, every equipment influence to passengers is calculated and the key facilities affect the LOS of subway station are required. Then the paper calculates the influence weight of facility status on comfort, safety and smoothness according to the influence of facilities status on pedestrian density. An evaluation model about LOS of subway station is established and the judgment matrix in the model is got by using YaAHP software. The evaluation model and method can provide reference to the configuration of key facilities in subway station and improve the LOS during the peak time.

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