Metro Station -Free Design Quantitative Evaluation Method Based on the Analytic Hierarchy Process

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ABSTRACT. Given the lack of mature systems and quantitative methods in China, the level of barrier-free design and construction of metro stations is evaluated and measured. Based on the analytic hierarchy process (AHP), the evaluation index system of barrier-free design of metro stations constructed three aspects: barrier-free travel, barrier-free access to information, and barrier-free public services. The initial evaluation matrix is established by pairwise comparison and scoring, and the weight values of each level index are calculated accordingly. Three metro stations' tests in Dalian with this evaluation method show that the evaluation system has practical operation performance. It can be used to guide the needs assessment before the barrier-free design and transformation of existing metro stations, or for the effective assessment of the barrier-free design of new metro stations, for the reference of relevant people.

Keywords: Barrier-free design, Urban rail transit, Evaluation system, Analytic hierarchy process, Metro station construction and operation

1 Introduction

As an environmental, fast and punctual rail public transportation with large passenger-carrying capacity, metro reflects the level of urban modernization. For the past few year, an increasing number of cities have expanded their metro network, and the passenger flow is increasing with each passing day. The metro station, as the valuable result of architecture, interior design and engineering construction, is the window for the city to show its elegant appearance. With the deepening of population aging in China, more and more people with disabilities have the need to travel by metro. However, the accessible designs of various metro stations are mixed and uneven, some good and some bad, and consequently it is difficult and inconvenient for the disabled and the elderly to travel by metro. Those accessibility design, separating the commonality of travel demands between special groups and ordinary users will eventually lead to a sharp fall in use value; a lack or a thoughtlessness of design somewhere can contribute to a lack of relevance and poor communication of information within the overall accessibility system.

The main reason accounting for this phenomenon is the lack of monitoring and evaluation mechanism built for accessibility design of metro stations, such as the implementation of accessible design, the evaluative feedback of accessibility system, the later maintenance and the management of related services. At present, it is stipulated in Article 9.8.1 of *GB 50157-2013 Code for Design of Metro*, the main national standard for metro station construction, that metro stations should conform to the relevant provisions of the current national standard, *GB50763 Code for*

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Accessibility Design. While the codes of national standard put forward the explicit design requirements for accessible facilities common in public buildings, given metro stations as relatively independent and special public transportation buildings, this standard does not have targeted design requirements for the environment in metro stations and passengers' travel behaviors, which cannot cover certain particularities of metro stations.[1]

Therefore, the establishment of a perfect evaluation system for accessibility design of metro stations is an important direction in the future for the overall planning and design departments of metro stations, especially in which the evaluation level of accessibility design of metro stations in China remains blank. Based on this, this paper constructs the evaluation index system of inner accessibility design in metro station (including traffic capacity, information environment and service) by applying the method of Analytic Hierarchy Process (AHP) on the basis of questionnaires and interviews, which can be used to evaluate the needs of accessibility design in existing metro stations before renovation, or to provide guidance for the effectiveness evaluation after the completion of new metro stations. [2]

2 Establishment of Evaluation Index System

2.1 Selecting Principle of Evaluation Index

According to different types of service groups and travel habits in metro stations, there are many elements of accessibility design types, including environment, facilities, services, etc. Therefore, it is necessary to select comprehensive and objective evaluation indicators to reflect the accessibility design conditions in metro stations, and follow several main principles such as pertinence, scientificity and comparability, so that there is a transparent structural relationship among indicators in all hierarchies.[3]

2.2 Structural Hierarchy and Index Meaning of the Evaluation Index System

Attention should be paid to passengers' behavior in accessibility design of metro station, and the types of barriers when passengers travel can be summarized into movement barrier, perception barrier and comprehension barrier. According to the author's investigations, interviews and thinking on metro stations in a certain number of cities, the travel deduction of passengers with obstacles and the induction of accessibility design in metro stations, and reference to relevant literature, three-layer hierarchical evaluation index systems are established, including three target hierarchies, eight criterion hierarchies and 26 index hierarchies.

Target hierarchy (A): Combined with the types of barriers encountered during travel, it is divided into three target hierarchies: travel accessibility, information acquisition accessibility and public service accessibility.

Criterion hierarchy (B): Indexes of three target hierarchies of barrier-free systems are subdivided into eight criterion hierarchies respectively.

Index hierarchy (C): Due to the relatively complex facilities, equipment and information environment in metro stations, the indexes belonging to each criterion hierarchy are subdivided into 26 index hierarchies in sequence, and the index meanings and qualitative and quantitative evaluation contents are given. See Tables 1 to 3 for specific contents.

Table 1. Evaluation hierarchy of barrier-free travel (Source of the table: drawn by author)

Target Hierarchy	Criterion Hierarchy	Index Hierarchy	Index Meanings and Qualitative and Quantitative Evaluation Contents
A1 Travel accessibility	B1 Access and ground	C1 Anti-skid treatment	Anti-skid treatment on the ground
		C2 Treatment on difference of elevation	Installation of reasonable (gradient, material) ramps at the entrances and exits with difference of elevation
		C3 Treatment on width	Enough width of gates, elevators, artificial gateways, etc. for wheelchairs to pass (the width is not less than 1.10 m)
		C4 Treatment on platform gap	Treatment measures on gaps when train is entering the platform, so that people with wheelchairs and crutches can pass smoothly
		C5 Passageway distance	Reasonable distance between the transference and the entrance and exit gates
	B2 Elevator and escalator	C6 Reasonable quantity	Reasonable quantity to make sure that passengers can pass through entrances and exits, station halls and platforms by elevators or escalators
		C7 Reasonable location	The location of elevators and escalators should be set in convenient and easy-to-find sectors of areas.
		C8 Reasonable capacity	Reasonable capacity suitable for the wheelchair to come in and go out (the depth of lift chair is not less than 1.60 meters and the width not less than 1.40 meters)

Table 2. Evaluation hierarchy of barrier-free public information acquisition (Source of the table: drawn by author)

Target Hierarchy	Criterion Hierarchy	Index Hierarchy	Index Meanings and Qualitative and Quantitative Evaluation Contents
A2 Information acquisition accessibility	B3 Visual direction	C9 Accurate and sufficient information	Accurate and unambiguous information of signs The locations of accessibility facilities are marked at key positions (such as entrances and exits).
		C10 Reasonable installation position of signs	Guide signs are installed in eye-catching positions (the joint point of people flow channel, the key link of people flow accesses, and the turnings and corners of people flow); The position of the guide sign is two meters above the ground.
		C11 Clearly visible and conspicuous signboards	High contrast of color matching, Clear fonts with sans serif, and material used to avoid glare
		C12 Sound indoor lighting conditions	/
	B4 Tactile information	C13 Reasonable layout of sidewalk for the blind	Sidewalk for the blind should be set at the starting points, end points and turning points. Layout of sidewalk for the blind should avoid such dangerous incidents as bumps against heads and stumbles.
		C14 Connected sidewalks for the blind	The sidewalks for the blind run through without disconnection, and the sidewalks for the blind at

			the entrance and exit is well connected with the those outside the station. Location and direction are convenient for visually impaired people to successfully reach travel behavior points with accessibility design.
		C15 Tactile information of inner station layout	Braille maps are set up or Braille route cards are provided.
		C16 Braille information	Braille information is arranged at key points, and Braille information is comprehensive and accurate.
	B5 Sound information	C17 Thorough information	/
		C18 Reasonable loudness	Sound can be clearly heard in the environment of howling from the metro vehicles.
		C19 Reasonable layout of point location	Loudspeakers are installed at the positions where guidance, warning and information supplement are needed.

Table 3. Evaluation hierarchy of barrier-free public service (Source of the table: drawn by author)

Target Hierarchy	**Criterion Hierarchy**	**Index Hierarchy**	**Index Meanings and Qualitative and Quantitative Evaluation Contents**
A3 Public service accessibility	B6 Barrier-free toilet	C20 Adequate space	The entrance and passage should be convenient for wheelchair to enter and rotate, and the rotation diameter is not less than 1.50 meters. The size of toilet seat should be reasonable, not less than 1.80m*1. 00m.
		C21 Reasonable Barrier-free Details	The toilet room should be equipped with toilet, wash basin, safety handrail, clothes hook and call-circuit button, etc.
		C22 Reasonable facility scale	Horizontal grabbing bar with a length of more than 70cm and vertical grabbing bar with a height of 1.40 meters are set around toilet seats The height of the clothes hook from the ground is not more than 1.20 meters. Call-circuit buttons are set at the wall surface beside the toilet and 40cm to 50cm high from the ground.[4~8]]
	B7 Service facility	C23 Low height arrangement	A low-height service counter should be set, convenient for disabled people in wheelchairs, with a height of 65cm to 85cm and a moving space for wheelchair users at the lower part. Low-level ticket selling machines, public telephones and so on are set.
		C24 Face recognition travel	"Face swiping" to enter the station quickly
	B8 Travel assistance service	C25 Barrier-free Assistance Service	Assistance service is set to help people with travel difficulties Help services can be booked through hot lines and Wechat official account.
		C26 Rental service	Rental services are provided such as wheelchairs, baby carriages and umbrellas.

3 Determination of Weight of Each Evaluation Index

In this paper, the method of analytic hierarchy process (AHP), which is less subjective, is adopted, that is, the relative importance of each index in the same hierarchy is compared in pairs by the form of correspondence survey, and then the matrix eigenvectors of different hierarchical structures are solved, so as to determine the weight value of each index in this evaluation system of accessibility design of metro stations.

The content of the questionnaire is mainly that each content of the eight criterion hierarchies and 26 index hierarchies is designed in the form of pairwise comparison , and the respondents are selected for correspondence survey, and Saaty 1-9 scaling method is used to reflect the importance index. Saaty 1-9 scaling method is shown in Table 4. The respondents mainly consist of postgraduates in design who have studied in and been engaged in accessibility design (7 people), operation staff of Metro Group (2 people), staff in inner metro stations (5 people), enthusiasts of urban rail transit (4 people), and disabled people (2 people), etc. The above people are comparatively familiar with the relevant content of accessibility design or metro station construction, and thus, their judgments are relatively scientific and accurate.[6]

Table 4. Saaty 1-9 scaling method (Source of the table: drawn by author)

Scale	Definition	Illustration
1	Equal importance	Both elements are of equal importance.
3	Moderate importance	The former is a little more important than the latter
5	Obvious importance	The former is obviously more important than the latter
7	Strong importance	The former is much more important than the latter
9	Extreme importance	The former is formidably more important than the latter
2, 4, 6, 8	Compromise of the above adjacent judgments	The comparison of the former and the latter influences is between the above two adjacent grades
Reciprocal of each number above	reciprocal number comparison	The comparison of the former and the latter influences is the reciprocal number above

The statistical results are calculated; the judgment matrix of analytic hierarchy process is constructed; the corresponding index weight is calculated; and consistency check is carried out. The calculation process is as follows.

Taking the criterion hierarchy of access and ground in the target hierarchy of barrier-free travel as example, the specific calculation steps are explained as follows:

Step 1 The statistical results are calculated and the judgment matrix is obtained:

	1	1.1487	1.1487	1.2457	1.6004
	0.8706	1	1.0845	1	1.2723
B2	0.8706	0.9221	1	0.6988	0.9642
	0.8027	1	1.4310	1	1.2457
	0.6248	0.7860	1.0371	0.8027	1

Step 2 Eigenvector of judgment matrix is solved by root method:

to the formula $\overline{W_i} = \sqrt[n]{\left(\prod_{j=1}^{n} b_{ij}\right)}$, i =1, 2, …, n can be obtained:

$\overline{W_1} = \sqrt[5]{(1 * 1.1487 * 1.1487 * 1.2457 * 1.6004)} = \sqrt[5]{2.63060}$ **=1.21342**

Similarly $\overline{W_2}$ =1.03736, $\overline{W_3}$ =0.88435, $\overline{W_4}$ =1.07429, $\overline{W_5}$ =0.83619

Step 3 The vector quantity is normalized $W_i = \overline{W_i} \sum_{i=1}^{n} W_j$, which can be obtained:

W_1 =1.21342/(1.21342+1.03736+0.88435+1.07429+0.83619)= 0.24049

W_2 =0.20560, W_3 =0.17527, W_4 =0.21292, W_5 =0.16573

Step 4 Consistency check:

The Maximum eigenvalue of matrix $\lambda_{max} = \frac{1}{n} \sum_{i=1}^{n} \frac{AW_i}{W_i}$,

Among which

AW_1 = 1*0.24049+1.1487*0.20560+1.1487*0.17527+1.2457*0.21292+1.6004*0.16573=1.20846

AW_2 =1.02883, AW_3 =0.88281, AW_4 =1.06882, AW_5 =0.83027

λ_{max} =1/5*(1.20846/0.24049+1.02883/0.20560+0.88281/0.17527+1.06882/0.21292+0.83027/0.16573)= 5.0190959

Step 5 Deviation consistency index of matrix $CI = \frac{\lambda_{max} - n}{n-1}$ = (5.0190959-5)/(5-1)=0.004773975

When n =5, random consistency index RI take 1.12

Consistency ratio index $CR = CI/RI$ =0.004773975/1.12=0.0042624777<0.1, meeting the consistency index.[4]

Therefore, the evaluation weights of five index index hierarchies under the B1 criterion hierarchy of access and ground are 0.24, 0.21, 0.18, 0.21, and 0.17, respectively.

By the same token, the weight coefficients of all indexes of accessibility design of metro stations can be calculated, and the calculated results have passed the consistency test, as shown in Table 5.

Table 5. Weight value of evaluation index for accessibility design of metro station (Source of the table: drawn by author)

Target Hierarchy	Criterion Hierarchy	Index Hierarchy
Travel accessibility	Access and ground 0.62	Anti-skid treatment 0.24
		Treatment on difference of elevation 0.21
		Treatment on width 0.18
		Treatment on platform gap 0.21
		Passageway distance 0.17

	Elevator and escalator 0.38	Reasonable quantity 0.34
		Reasonable location 0.36
		Reasonable capacity 0.30
Information acquisition accessibility	Visual direction 0.65	Accurate and sufficient information 0.39
		Reasonable installation position of signs 0.27
		Clearly visible and conspicuous signboards 0.23
		Sound indoor lighting conditions 0.11
	Tactile information 0.21	Reasonable layout of sidewalk for the blind 0.44
		Connected sidewalks for the blind 0.32
		Tactile information of inner station layout 0.13
		Braille information 0.10
	Sound information 0.15	Thorough information 0.40
		Reasonable loudness 0.30
		Reasonable layout of point location 0.30
Public service accessibility	Barrier-free toilet 0.18	Adequate space 0.39
		Reasonable Barrier-free Details 0.32
		Reasonable facility scale 0.29
	Service facility 0.23	Low height arrangement 0.87
		Face recognition travel 0.13
	Travel assistance service 0.60	Barrier-free Assistance Service 0.76
		Rental service 0.24

4 Application of the Evaluation System to Case Analysis

This paper chooses three metro stations built and operated in different periods of Dalian Metro to compare and evaluate, and test the actual operation of the evaluation system.

4.1 Case Overview

The cases in this paper are selected as follows: Stations of Dalian Metro Line 3 such as Quanshui Station, Stations of Line 1 such as Huizhanzhongxin Station, and Stations of Metro Line 13 such as Haiwangaozhong Station.

Quanshui Station was completed and operated in mid-2003, located in Quanshui Street, Ganjingzi District, the northern center of the city, near Quanshui Bus Hub and residential areas; Huizhanzhongxin Station was completed and operated in early 2016, located in Xinghaiwan Street, Shahekou District, downtown, near Xinghai Square, Modern Museum and other scenic spots and landmarks; Haiwangaozhong Station was completed and operated at the end of 2021, located in Fengrong Street, Pulandian District, Dalian, near Pulandian Wanda Plaza and other commercial centers, and is the station with the largest number of machines on Line 13. The three metro stations have a large passenger flow, and they are the first rail transit lines in Dalian in the early days, the first batch of rail transit lines in urban areas and the newly built metro stations in recent years, which are of certain periodicity and reference significance in the evaluation of accessibility design and construction level in different periods. The survey on the accessibility design of three metro stations is shown in Fig.1.

In the on-the-spot investigation of three metro stations, 10-point scoring method is used to score each index designed in the preceding part of the text respectively. The scoring criteria are: excellent—the index design is well-rounded, with score of 9 to 10 points; good—the index design is basically reasonable with score of 7 to 8 points; general—4 to 6 points, and poor—1 to 3 points; See Table 6 for the score values.

Fig. 1. Investigation and survey on the present situation of accessibility design and construction of metro stations on three lines (Source of figure: taken at the scene by author)

Table 6. Scoring of field investigation (Source of the table: drawn by author)

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13
Quanshui Station	3	2	2	9	7	7	5	6	4	3	3	7	4
Huizhan-zhongxin Station	7	6	9	9	10	8	7	10	9	10	8	9	8
Hai-wangaozhong Station	8	6	9	9	9	8	10	10	10	10	8	9	6
	C14	C15	C16	C17	C18	C19	C20	C21	C22	C23	C24	C25	C26
Quanshui Station	2	2	2	3	7	4	3	3	3	2	0	5	4

Huizhan-zhongxin Station	7	6	4	6	9	8	9	7	7	8	0	10	7
Hai-wangaozhong Station	7	7	4	8	8	8	9	8	8	8	0	10	7

According to the evaluation above, combined with the weight coefficients of each indicator above, the scores and comprehensive scores of public service accessibility, information acquisition accessibility, public service accessibility of the three metro stations can be calculated, as shown in Table 7.

Table 7. Scoring value of accessibility design level of three metro stations (Source of the table: drawn by author)

	Overall Score	**Target Hierarchy**	**Criterion Hierarchy**	**Index Hierarchy**
Quanshui Station	31.25	10.56	11.19	9.5
Huizhanzhongxin Station	63.89	16.39	23.48	24.02
Haiwangaozhong Station	65.79	17.54	23.62	24.63

It can be seen from the calculation results that the accessibility design of Huizhanzhongxin Station and Haiwanzhongxue Station is far superior to Quanshui Station built earlier, and Haiwanzhongxue Station is slightly superior to Huizhanzhongxin Station. This is consistent with the results of actual investigation and interview, which proves that the actual operation of the evaluation system is good in performance.

5 Conclusion and Enlightenment

From this rating and research work, relevant conclusions and enlightenment are obtained as follows:

(1)There are at least two points in this evaluation index that can be refined and optimized.

Firstly, the evaluation definition of accessibility equipment and facilities in this evaluation index obtains quantitative indicators through looking up literature and ergonomic calculation, while it is only through interviews and induction that the evaluation of information environment such as visual, tactile and auditory sense can obtain qualitative indicators. With the popularization of information accessibility and the advancement of related research, it is expected that the standardization, quantitative construction and evaluation system of information accessibility in domestic metro stations will be improved and optimized.

Secondly, there is room for refinement and perfection in designing "reasonable" related indicators, which requires deep observation and thinking by evaluators. Due to numerous and complex influencing factors of accessibility design in metro stations, whether a certain design is "reasonable" is also affected by many factors such as regional characteristics, passenger flow intensity, passenger attributes, combination with other buildings, etc. Therefore, there is room for refinement and perfection, and the evaluator must think deeply about the actual usage experience of relevant designs. Taking the two indicators of "reasonable layout of sidewalks for the blind" and "connection of sidewalks for the blind" as examples, as shown in Fig.2, the author observed that a metro station has set up connected warning blind sidewalk along both sides of the platform, passing through the gate machine on the blind sidewalk of the station hall. These seem to conform to the indicators, but when blind people actually use it, it is impossible for them to judge the direction at the blind sidewalk fork, that is, which side should be taken to go up and down; When waiting for the train, it is impossible to independently judge the appropriate and accurate position to enter the carriage, and to pass through the gate machine at the station hall to travel, but they will use the free restricted lane. Therefore, the design is unreasonable and can not take excellent scores, while the blind sidewalk design at the platform in Fig.3 avoids the above problems relatively more effectively.

Fig. 2. Blind sidewalks which seem reasonable but have problems (Source of figure: taken at the scene by author)

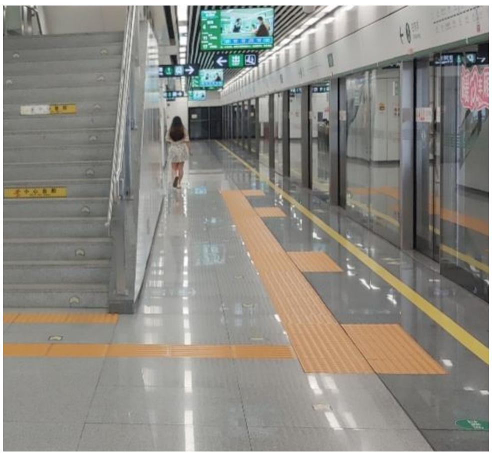

Fig. 3. Blind sidewalks with layout of more guidance (Source of figure：taken at the scene by author)

(2) The evaluation and judgment system of accessibility design should contain multi-dimensional professionals. Under the concept of universal design, accessibility design is designed for all people in need, and anyone can use it for convenience. Therefore, it is meaningful to obtain evaluation from different levels of people and various types of passengers in metro station service structure, and respondents of various status with different professional knowledge, skills and work experience have different cores of judgment system, which can make up for the insufficiency of mutual thinking in selecting indicators, index weights and actual evaluation, making multi-index and multi-factor evaluation more systematic and scientific. Finally, the internal consistency is verified by consistency check, and the reliability of the investigation is verified.

6 Conclusion

China's urban rail transit construction has changed from "strengthening the construction of urban rail transit network" during the 13th Five-Year Plan period to "gradually shifting from emphasizing construction to paying equal attention to construction and operation" during the 14th Five-Year Plan period. The consolidation and implementation of modern accessibility design in metro stations is the focus of mutual implementation of construction and operation. It is hoped that the follow-up research can further optimize and improve the determination of index system and weight value, and explore the modern design related to smart city rail transit in the future on the basis of evaluating and quantifying accessibility design of metro stations.

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