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Research on Passenger Density of Urban Rail Transit Based on Human Factors

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Abstract

Starting from the different levels of space requirements of passengers in urban rail transit carriages, this paper puts forward the standard density for subway carriages based on passenger space comfort by means of theoretical analysis, questionnaire survey and on-site investigation, and preliminarily studies the method for determining the standard passenger density for lines with more luggage.

Keywords

Urban rail transit;Passenger density;Human factors.

1. Introduction

With the improvement of living standards, people's demand for rail transit travel mode has changed from "functional" to "comfortable".Compared with the initial stage of subway construction, the passenger's demand for personal space is obviously increased, and the requirement for comfort is also getting higher and higher[1].At present, passenger density standard of urban rail transit in China is in a period of change. The standard (6 person /m2) implemented for many years in the Code for Design of Subway (GB50157-2003) can no longer meet people's requirements for travel comfort.In some local standards, the density has been increased to 5 person /m2 [2] .It can be seen that it is of great significance to have a new look at the passenger density in the new era of subway construction.

2. Passengers' Demand for Space

The passenger's demand for space should start with the basic size of the human body, considering the most basic space to meet the size of the human body, the activity space to meet the basic activities of the human body, the personal space to meet the personal attributes , and the interpersonal space to meet the social attributes .

2.1. Basic Space

2.1.1. Human Body Size

《Chinese adults body size GB10000-88》 stipulates that the "chest thickness" and "maximum shoulder width" of the 95% of men aged 18-60 in China are 24.5cm and 46.9cm respectively.Most of the current pedestrian traffic model is based on “maximum shoulder width” and “chest thickness”, and the projected area is the size of the human body[3]. In fact, the elbow of the left and right arms of the human body protrudes farther than the shoulder width.The foremost point of the human body may be the chest or abdomen, and the last point may be the buttocks or shoulders. The maximum longitudinal dimension is also larger than the chest thickness.In view of this, domestic scholars obtained a sample of the small sample to obtain the

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percentage increase of the "maximum body width" and "maximum body thickness" of the human body relative to the "maximum shoulder width" and "chest thickness".According to this method, based on the 95% of the men's design size specified in the national standard 《Chinese adult human body size GB10000-88》, the revised "maximum body width" and "maximum body thickness" of the human body are calculated.They are 53.935 cm and 30.380 cm, respectively.

In 2009, the China Institute of Standardization organized and completed the latest pilot survey of human body size sampling for Chinese adults. The sampling adopted advanced three-dimensional human body scanning technology. Compared with the 1988 standard, more measurement indicators can be directly obtained, such as the maximum body breadth of horizontal projection of human body and the maximum thickness, which are all direct measurement indicators without correction, making the data more accurate.The adult human body sizes are shown in Table 1.

Table 1. Maximum body width and thickness of adult (cm)

Gender	Maximum body width	Maximum body thickness
Male	52.7	34.0
Female	49.7	32.9

From the data in Table 1, it can be seen that compared with the above-mentioned maximum body breadth and the maximum thickness correction value, the maximum body breadth value does not change much, but the maximum thickness value increases obviously, reflecting the fact that the Chinese body size increases.

2.1.2. Clothing Influence

The space that meets the basic size of the most human body should be based on the basic size of the passenger when the chest is standing upright, taking the winter dress as standard, considering the dressing but not the baggage.

In summer, passengers wear less and have a small body size, but they are far away from others psychologically.This kind of psychological conflict is to avoid direct contact with the skin and keep a distance due to the spread of sweat in summer.In winter, although the clothing takes up a large space, due to the separation of the clothing, direct skin contact will not occur even if the clothing is pressed against each other, and the psychological repulsion force is small.

Therefore, when studying the basic density, the "winter dress + no baggage" size should be used as the standard, which not only leaves a margin for the psychological distance of the summer passengers, but also meets the need for thickening of the winter dress.

(1)Under normal circumstance.U.S. related standard SAE J833- 1989 stipulates that the additional value of clothing thickness to shoulder width and chest thickness is 7.5cm, which can meet the requirements of winter clothing.According to the measurement data of domestic scholars, as shown in Table 2, considering the growth of human body size in our country, the added value of dressing and body size growth is set at 10 cm[4]. According to the latest human body size data, the human projection shape is simplified into an elliptical shape, and the basic projection space of the human body under the winter dressing condition is 0.222 m2, and the corresponding density is 4.513 persons/m2.

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Table 2. Maximum body width and thickness of adult under Different Dressing Condition (cm)

Dress	Maximum body breadth increment		Maximum body thickness increment	
	Mean value	Variation range	Mean value	Variation range
Spring and Autumn -Summer	3.8	2.5~5.6	2.3	1.0~4.0
Winter-Summer	9.3	6.2~11.8	8.3	7.3~10.6

(2)Under difficult circumstances.Under difficult situations, the clothing increment of 7.5cm per person will be compressed by half. At this time, the clothing will contact and squeeze each other, but the human body will not feel obvious pressure. At this time, the standing mat density is 5.24 people/m2.

(3)Luggage factor.According to the measurement results of domestic scholars, the dimension increment values of body width and body thickness for pedestrians carrying different luggage are shown in Table 3.

Table 3. Increment of Pedestrian Individual Space Size under Different Luggage Factors (cm)

Luggage conditions	Body breadth increment	Body thickness increment
Single shoulder bag	4.3	10.8
Backpack	1.3	16.3
Handbag	4.7	17.3
Two-handed bag	10.0	17.3
luggage case	21.0	73.8
Backpack and Handbag	5.5	24.9
Luggage case and Handbag	26.4	82.7

There are many suggested values for the space occupied by pedestrians at home and abroad.In this paper, the latest pedestrian size in China is selected. Based on the "maximum body breadth" and "maximum thickness", considering the body width and body thickness increment of individual pedestrians under different clothing and luggage factors, the individual space occupied area of pedestrians is calculated according to oval projection, as shown in Table 4.If the small luggage carried by passengers is taken into account, the corresponding passenger density is 3.62 persons /m2 according to the "winter dress+single shoulder bag".

Table 4. Individual Space Size under the Combined Effect of Dressing and Luggage Factor (m^2)

Luggage conditions	Dressing conditions		
	Summer dress	Spring and Autumn dress	Winter dress
No luggage	0.141	0.162	0.206
Single shoulder bag	0.201	0.226	0.277
Backpack	0.213	0.240	0.291
Handbag	0.231	0.259	0.312
Two-handed bag	0.253	0.282	0.337
Luggage case	0.624	0.672	0.757
Backpack and Handbag	0.269	0.299	0.356
Luggage case and Handbag	0.725	0.777	0.868

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2.2. Human Activity Space

In the calibration of adult human body size in our country, the standing posture size is measured in the state of holding out one's chest and standing upright.However, maintaining the same standing posture for a long time will accelerate the fatigue , especially in the high-density crowd, which will make the passengers feel anxious and agitated psychologically.Only by ensuring the basic free space can passengers adjust slightly and relieve the long-term tension in the same part[5].

When the density in the carriage is high, the area occupied by the passengers' feet is almost the same, and the passengers can keep their bodies balance depending on service facilities such as handles.

Based on the human body size in the national standard, the spatial scale of standing posture activities is shown in Fig.1.

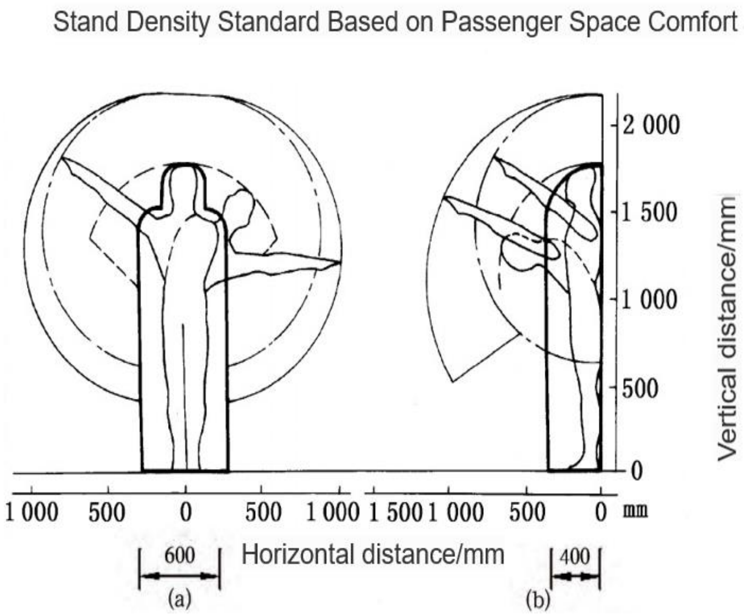

Fig 1. Spatial scale of human standing activities

As can be seen from Fig.1, when the human body stands upright, the slight range of motion is about 0.6m in the transverse direction and 0.4m in the longitudinal direction, with a corresponding density of 5.3 persons/m.At this time, passengers can achieve the use of handles or handrails to stand, change feet, small rotation and other small movements.Considering that the density of clothing is 3.64 people /m2, the density increases to 4.16 people /m2 when the clothing is compressed by half.

2.3. Balance Space

Passengers have both individual attributes and social attributes.Among them, the individual attribute corresponds to the individual space demand and the social attribute corresponds to the interpersonal space demand[6].

3. Expected Space for Passengers

3.1. Subjective Questionnaire Analysis

Through on-site investigation and network investigation, a total of 460 questionnaires were collected for passengers' perceived space comfort (congestion degree) (see Table 5), of which 418 were valid, accounting for 90.9% of the total sample.The subjective satisfaction of

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passengers with different congestion conditions can be obtained by analyzing and investigating the results.

Table 5. Passenger Space Comfort under Different Congestion Conditions

Description of Passenger Congestion	Very comfortable	More comfortable	General	Not very comfortable	Very uncomfortable
Passengers can move freely, which is very loose.					
Passengers can read books and newspapers which is more loosely.					
Some passengers can read books and newspapers with a certain degree of relaxation.					
Passengers can move a little, which is a little crowded.					
Passengers in contact with the body need to be staggered, which is relatively crowded.					
Passengers have difficult activities and are very crowded. Passengers waiting for boarding are difficult to enter.					

As shown in Table 5, the six crowding conditions in the table correspond to six densities respectively.Comfort rating of "average" and above is considered satisfactory.According to the subjective feelings of passengers on the description of congestion, the satisfaction degree of passengers under the condition of isotactic density is obtained, and the fitting equation is:

$$y = 0.1141x - 1.5785x + 6.7729x - 11.972x + 8.5001x + 96.304 \ (R=1) \quad (1)$$

In the formula:X- passenger density, single :Person/m2;

Y-passenger satisfaction, single:%

Applicable scope : 1 < x<7 persons /m2.

According to the fitting equation, the corresponding vertical mat density under different satisfaction conditions is shown in Table 6.

Table 6. Stand Density Corresponding to Different Satisfaction

Satisfaction	97	95	90	85	80	75	72	70	56	20
Stand density	3	3.3	3.7	4	4.2	4.4	4.5	4.6	5	6

As can be seen from Table 6, when the passenger density is 3 persons /m, i.e. the close distance of interpersonal space, 97% of passengers are still satisfied.This shows that the expected value of comfortable space for passengers is reduced in the enclosed space of the carriage.Therefore, the psychological comfort space and the psychological safety space of passengers listed in table 5 are adjusted to 2 persons /m and 3 persons/m respectively to make them more suitable for the evaluation of space comfort in subway cars.

According to the results of the survey, the currently widely adopted standard of 6 persons /m2 can only meet the basic space corresponding to human body size, and cannot meet the comfort

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needs of passengers.In order to ensure the comfort level to satisfy most passengers, it is suggested to set the density standard of standing seats at 4.5 ~ 5 persons/m2.

3.2. Passenger Stagnation

Based on the on-site investigation of Peking subway operation lines, it is found that the average density of the corresponding carriages is 5.5 persons /m2 when passengers are stranded on the platform during the morning and evening rush hours on weekdays.Objectively, it shows that when the average passenger density in the compartment reaches 5.5 persons /m2, the overall congestion level of the compartment has reached the tolerance limit of passengers for space congestion. Although the density of the door area may have reached 7-8 people/m2 at this time, from the perspective of the average density response vehicle design passenger load, this paper still uses the average distribution level of density as the evaluation basis.

4. Density Standard Based on Human Factors

4.1. Density Standard Based on Passenger Space Comfort

This paper analyzes the comfort density of passenger space under various requirements from the perspectives of human body size, dress and luggage correction, basic human activity space, psychological safety space, psychological comfort space, passenger expectation space and detention, etc., as shown in Table 7.

According to the investigation results of passenger passenger density and passenger perceived space comfort under various angles, the recommended human body space level and corresponding density are obtained, as shown in Table 8.

Table 7. Comfort Density of Passenger Space under Different Angles and Requirements

Angle	Requirement	Density(human/㎡)
Body size	Dressing in Winter under Normal Conditions	4.513
	Dressing in Winter under Difficult Conditions	5.24
Carrying luggage correction	Winter dressing and Single shoulder bag	3.62
Activity space	Consider dress	3.64
	Slight movement when standing up, clothes are compressed by half.	4.16
Margin space	Psychological safety space	1.89
	Psychological comfort space	0.79
	According to the revised psychological safety space of customer satisfaction	3
	According to the revised psychological comfort space of customer satisfaction	2
Detention phenomenon	Average stand density in the carriage when the platform is stranded.	5.5
Passenger's Expected Space	According to the results of the questionnaire survey, meet the requirements of most people.	4.5~5

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Table 8. Stand Density Standard Based on Passenger Space Comfort

Stand density class	Stand density (human/㎡)	Describe	Satisfaction(%)
Level 1	≤2	Meeting Psychological Comfort Space	98
Level 2	3	Meeting Psychological Safety Space, there is a certain degree of looseness	97
Level 3	4	Small range of activities when dressing in winter	85
Level 4	5	In winter, the clothes are occasionally contacted but not squeezed. In summer, the clothes can be moved in a small range. Passenger retention began to occur. When considering carry-on luggage, 4.5 is preferable.	56
Level 5	6	Satisfy the basic space of passengers, and make clothes contact when dressing in winter. When wearing a small amount of clothes, the body parts occasionally touch but will not squeeze.	20
Level 6	7	The endurance limit of passenger comfort, the body is in a squeezed state.	12

4.2. Special Circumstances Revision

Due to the different characteristics of passengers on different routes, passengers carry different luggage.For example, if passengers are carrying more luggage when passing through the railway station or the line attached to the airport, the passenger space that only guarantees the basic size of the human body can no longer meet the requirements.According to the specific conditions of luggage carried on different routes, appropriate storage should be made for passenger space.Specifically, the weight can be distributed according to the proportion of luggage carried by passengers on the route. Based on the most basic space of the human body (summer clothing), the projected area under the condition of carrying luggage should be:

$$S = \sum_{i=1}^{k} w_i S_i \qquad (2)$$

In the formula: S - per capita area, unit: m2;

W i - the proportion of passengers carrying different luggage.

Si - the basic space size occupied by different luggage traveling with in summer dressing , unit: m2.

5. Conclusions

(1)Based on the theoretical analysis of personal space under different requirements , combined with the results of subjective questionnaires, and the density of passengers stranded in the survey, the standard of passenger density based on human factors is obtained.For long-distance routes, travel time will accelerate human body fatigue, and the reduction of comfort level is needed. This reduction is mainly reflected in time rather than space. Therefore, when studying the density standard based on passenger space comfort, long-distance routes need not be specially reduced, and folding seats can be considered to reduce fatigue.

(2)Found in the field investigation that ,during the morning and evening peak hours of the working day, the density of passengers standing in the door areas of individual sections can reach 9-10 persons /m2, which is a serious congestion state and the comfort of passengers is extremely poor.It is suggested that during rush hours, no-seat carriages should be set up for

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commuter passengers so that passengers can choose between comfort requirements and driving force.The invention can relieve the congestion of carriages and effectively reduce the detention of passengers on the platform.

(3)Through analysis and calculation, this paper also obtains the calculation formula of the density based on the special lines carrying luggage, such as stations and airports. For the lines with commuter flow, in the morning and evening peak hours, people's demand for time cost is greater than that for comfort demand; At this time, it is conceivable to add a non-seat car or setting up a folding seat to cope with the impact of concentrated passenger flow.

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