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Build a Comprehensive Ride Comfort Index System for Subway Trains

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Abstract

Rail transit is vital for the development of large cities. Comfort is a key factor for urban residents when choosing subway trains for their travel, so the study of ride comfort is also increasingly important in the field of rail human factors. Based on the model of a human-computer interaction system, this paper proposes an analytical model of the influencing factors of rail transit ride comfort; based on this analysis model, from the perspectives of passenger characteristics and the attributes of the indoor and outdoor environment of the subway train passenger compartment, combined with the guiding principles of index selection, a subway train ride comfort system is established, which covers five aspects: facility attributes, microclimate environment, operation performance, passenger crowding, and visual quality.

Keywords*: Subway train, ride comfort, index system, passenger compartment.*

I. Introduction

The rapid development of rail transit has facilitated major cities to move towards metropolitan areas (MA) [1], and driverless subway trains are being used in rail lines around the world as subway lines increase [2,3]. The growth rate of driverless lines is expected to triple, reaching more than 1,800 km by 2025 [4,5]. This shows that urban rail transit plays a vital role in the development of cities. In addition, the growth of urban rail transit lines is conducive to alleviating traffic congestion while attracting urban residents to choose rail transit for their travel. For passengers choosing urban rail transit to travel, the factors considered are mentioned in EN 13816 [6]: convenience, access to information, and ride comfort. Ride comfort is one of the key factors to attract passengers and falls into the rail human factor area.

Rail human factors involve relevant personnel in the study, including signallers, controllers, drivers, train crews, planners, engineers, maintenance workers, lookouts, safety controllers, and passengers [7]. Research on train drivers (fatigue, attention and signals in road driving/cognitive and performance models of train drivers) deals with train drivers' alertness, perception, and their recognition and response to signals and signs, which is a relatively well-established area of research [7]. Another topic under long-term and continuous research is ride quality and passenger comforts [7], such as ride comfort in high-speed trains [8, 9], the effect of vehicle tilt on passenger comfort [10], and the effect of vibration direction on passenger comfort [11,12]. This is a traditional part of the study of human factors in rail transportation.

This paper aims to establish an index system for subway train ride comfort. First, based on the analysis of the existing human-computer interaction model, an analysis model of the factors influencing ride comfort is proposed. Secondly, a subway train ride comfort index system is established, based on the analysis model of the factors influencing ride comfort, combined with the principle of index selection, by analyzing the characteristics of subway trains and the needs of passengers.

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II. Analysis Model of Factors Influencing Ride Comfort and Principles of Index Selection

Cane juice samples were subjected to centrifugation using a Remi R-8 C batch-type laboratory model. This was operated at 6000 rpm, attaining 2000g at the bottle tip. For every run it was set for 5 minutes. Optimization of the centrifuge operation is a function of design and so was not carried out. Only the various effective parameters due to centrifugation of cane juice have been observed in the present study. Purity measurement of cane juice was done using a Sucromat in a conventional way. A Brookfield RVT viscometer was used to measure the apparent viscosity difference at 50 rpm using spindle No.1 The ICUMSA colour measurement was done using TEA-buffer and membrane filter as described elsewhere. The colour measurements were carried out on an ELICO spectrophotometer.

2.1 Analysis model of influencing factors

Ride comfort is an important concept for evaluating the ride quality of transportation, and initially, only vibration was used as an indicator for evaluating ride comfort. For example, in human factors studies of automobiles and rail transportation, rider comfort is a relationship between vibration and comfort [13, 14]. On the basis of this, the technical standard on human vibration (ISO 2631-1) was developed [15]. In human factors of rail transit, the extents of train ride comfort extend to noise, odor, temperature, humidity, and illumination [16-18]. This continuous development process of the extension of rail transit ride comfort is essentially the result of the interaction between passengers and multiple elements of the internal and external environment of the train, i.e., the interaction between passengers and the environment inside and outside the passenger compartment of the train belongs to the research category of human-system interaction.

In the field of human factors research, the human-system interaction model is used to describe the process of human processing of information. Perception, cognition, and behavioral feedback constitute the information processing chain, and these three parts form a cycle [19, 20]. The model assumes a continuous flow of interactions between humans and the system. The interaction process begins with the collection of information from the relevant machine (or environment) by the sensory system (including visual, tactile, olfactory, auditory and vestibular systems) [19].

Based on the human-system interaction model, an analysis model of the influencing factors of rail train ride comfort is proposed (as shown in Figure 1). The model demonstrates the interaction between passengers and the internal and external spatial environment of the train compartment as a system during the operation of the rail train, i.e. the response of the passenger's perceptual system (including vision, touch, smell, hearing and body sensation, etc.) to the stimulation of environmental elements inside and outside the rail train compartment. The factors and indicators obtained from this model analysis can be used to evaluate and optimize the characteristics of the passenger compartment environmental system of the train.

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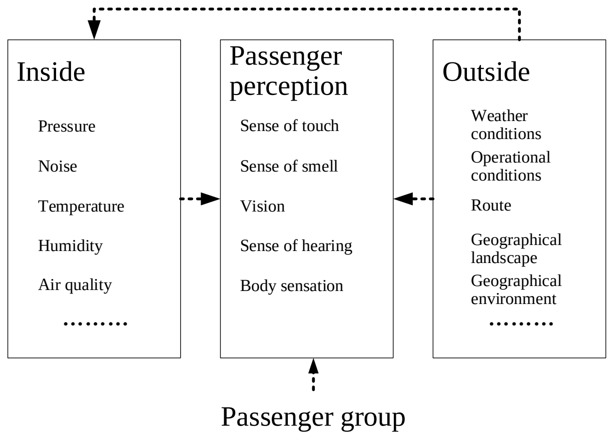

Fig 1: Analysis model of the factors influencing the ride comfort of rail transit trains

2.2 Indicator selection principles

2.2.1 Dominance

There are many factors affecting the ride comfort of subway train passenger compartments, and the relationship between the levels of each factor is complex. If all the indicators affecting ride comfort are listed without any distinction, it will lead to a confusing system of indicators of ride comfort. Therefore, the evaluation system needs to be established with a clear purpose, focusing on the selection of indicators that are dominant and have relevance to passengers and train passenger compartments. In short, the main evaluation indicators should be obtained.

2.2.2 Operability

In selecting the indicators of subway train ride comfort, the operability of the indicators should be considered, which can also be understood as the indicators are easy to measure. The study of subway train ride comfort has two main elements: passengers and subway train passenger compartments. There are many indicators in these two elements, and if operability is not considered, it is difficult to identify the advantages and disadvantages of the indicators, thus making it difficult to prioritize and effectively improve the ride comfort of a subway train. Therefore, considering the operability of indicators can better evaluate the ride comfort of subway trains.

2.2.3 Wholeness

The index system of subway train ride comfort should reflect many aspects of passengers in the process of riding, and is a top-down, macro-to-micro multi-level, interconnected system. When selecting indicators, we should focus on the logic between indicators and also consider the wholeness. In other words, it should be able to accurately reflect the main features of ride comfort from different aspects, and also reflect the inner hierarchical relationship between indicators to form an organic whole.

III. Comprehensive Ride Comfort Index System for Subway Trains

This is an index system of ride comfort of subway trains covering five dimensions: facility attributes, microclimate environment, operational performance, passenger behavior and density, and visual quality (see Figure 2). It's established based on the analysis model of the factors influencing ride comfort, combining the external and internal environmental elements of the subway passenger compartments and the characteristics of passenger behavior, and using the index selection principle.

3.1 Subway train ride comfort indicators

3.1.1 Facility attributes

Subway train passenger compartment can be divided into the seating area, aisle area, and doorway area, and the facilities in these areas are mainly: seats, handrails, and hoops. Passengers interact with the facilities through the sense of touch (system) and body sensation. Based on the analysis model of factors influencing rail train ride comfort, the author clarifies the impact of the facility attributes in these areas on passenger comfort. For example, the size attributes of the seats, handrails and hoops affect the comfort of the passengers. Passenger comfort increases when the convex curvature of the seat lumbar and the concave curvature radius of the seat surface match the natural curvature of the human back and hips, and when the height of the rings and crossbars meet the natural grip and ease of passage for most passengers [21, 22]. In terms of the softness of seat cushions, backrests and door walls, the human body pressure distribution can be used to describe passenger comfort. When the contact area is large and the values of average pressure, maximum pressure gradient and average pressure gradient are small, passengers are indicated to be comfortable [21].

In addition to the size and softness attributes of subway passenger compartment facilities, the spatial layout attributes of the facilities are also important factors that affect passengers. The irrational spatial layout of the facility will result in uneven distribution of passengers in the various areas of the passenger compartments. If there are more handrails and hoops in the entrance area than in the aisle area, most of the passengers will gather in the entrance area, which makes the passengers crowded and feel very uncomfortable.

3.1.2 Microclimate environment and air quality

Microclimate refers to the climatic conditions in a given environment, including temperature, humidity, wind speed, and thermal radiation[23]. Microclimate affects human comfort by interacting with microclimate conditions through the human body's skin sensory and respiratory systems. The microclimate of subway train passenger compartments is no exception, and poor conditions can lead to increased passenger fatigue and affect passenger mood and health.

These four climatic conditions can be substituted for each other in their effects on the human body. For example, the heat gained by the body by thermal radiation can be offset by low temperatures; people will not feel very hot if the temperature increases while the corresponding airflow speed increases [23]. Changes in metabolic rate and human thermal radiation show that human comfort is affected by temper-ature and humidity: partial pressure of water vapor in the air and ambient temperature are closely related to human heat dissipation; low temperature and high humidity increase human heat dissipation and can cause frostbite; high temperature and high humidity cause the body to lose its thermal evaporation function and make people feel uncomfortable [23].

Air quality affects human comfort through the exchange of water and heat between the human body and the environment and the exchange of gases during breathing. The quality of air in the passenger compartment of subway trains refers to the content of each component in the air, mainly including CO_2, NO_2, SO_2, CO, and various particulate matter. Among them, CO_2, which is closely related to human metabolism, is the main influencing factor [24]. Jokl et al. proposed a CO_2 evaluation scale where CO_2 affects people in the range of 900-1,800 mg/m3, and for sensitive populations (e.g., asthmatics), the range of CO_2 in the air is within 900-1,080 mg/m3, with a tolerance range of 1,080-1,800 mg/m3; and the upper tolerance limit is at 2,800 mg/m3 [25, 26].

3.1.3 Vehicle operation performance

The main factors that cause human discomfort during subway travel, in terms of operational performance, include:

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vibration, noise, and air pressure. In addition to affecting passenger experience, these factors may also affect passenger health.

The human body responds to vibration in two main ways: vibration magnitude and vibration frequency. The vibration magnitude, which is caused by unreasonable suspension devices and up and down due to stiffness, can be optimized and eliminated; in terms of vibration frequency, the smoothness through a single frequency is used as a comfort indicator [8]. The calculation equation [27] is as follows.

$$w_i = 7.08\sqrt[10]{\frac{A_i^3}{f_i}F\left(f_i\right)} \tag{1}$$

Where: W_i is the smoothness index; A_i is the vibration acceleration; f_i is the vibration frequency; F(f_i) is the frequency correction factor.

Noise that affects human hearing is manifested in the frequency, amplitude, and duration of the vibration of the sound waves [8]. Exposure to strong noise environments can damage human hearing and lead to related diseases. In rail operation, noise is classified by its source: wheel-track noise, power equipment noise, pneumatic noise, noise from the receiving system, and excitation noise [28]. These noises, if too loud and long-lasting, can cause mood irritation, physical fatigue, and even psychological and physical damage to passengers [29, 30]. According to GB/T12816-2006 "The limiting value and measurement method for the interior noise in the railway passenger coach": the noise of all passenger compartments is no more than 65dB (A) when the train is running and no more than 60dB (A) when it is stationary.

In addition to noise, air pressure also affects the sense of hearing. If the change of air pressure in the passenger compartment of a railway train exceeds a certain value, it will irritate the eardrums of passengers and make them feel uncomfortable in their hearing. For example, a survey of Shinkansen in Japan showed that "ear discomfort" occurs when the pressure inside the train is below -0.2 kPa; "ear discomfort" also occurs when the pressure reaches +0.2 kPa when the doors are opened; when the pressure exceeds +0.5 kPa, passengers experience extreme discomfort [8].

In terms of the method of evaluating passenger comfort by air pressure changes, human physiological needs are considered in addition to the magnitude of pressure changes and the rate of pressure changes [31]. This evaluation method is applied by Japan and European and American countries, and the specific pressure limits are: maximum pressure change amplitude, for which both Japan and Germany require 1,000 Pa, 700 Pa in 1.7s in the US, and 4,000 Pa in 4s in the UK; maximum pressure change rate, for which Japan and Germany require 200 Pa/s, 410 Pa/s in the US, the UK requires an adjustment time of 4s for eardrum pressure [32, 33]. Chinese trains adopt Japanese and German standards, which stipulate that the maximum rate of pressure change in the passenger compartment is 200 Pa/s and the maximum amplitude of pressure change does not exceed 1,000 Pa [8].

3.1.4 Passenger crowding

During a subway ride, passenger behavior includes entering the compartment, traveling in the compartment, waiting and exiting the compartment. Crowding among passengers is inevitable in these behaviors. The feeling of crowding between passenger groups is perceived through the physical size of the body and the mind, which challenges and disrupts personal space, while passengers feel irritated. The concept of passenger crowding is a controversial issue in the literature in the rail domain [35] and is defined as an experience that can be measured based on passenger density and the capacity of the train [34-35]. Previous literature on crowding experience assessment has focused on measures of passenger density [34], with density generally referring to objective physical characteristics [36], but this does not convey the personal subjective perception of crowding [34]. Therefore, crowding has two meanings: on the one hand, density or available space with objective components; on the other hand, subjective perception of available space and existing number of people [34]. Passenger densities of 2-3 persons/m2 are considered comfortable, 5 persons/m2 as uncomfortable, and > 8 persons/m2 as intolerable [37].

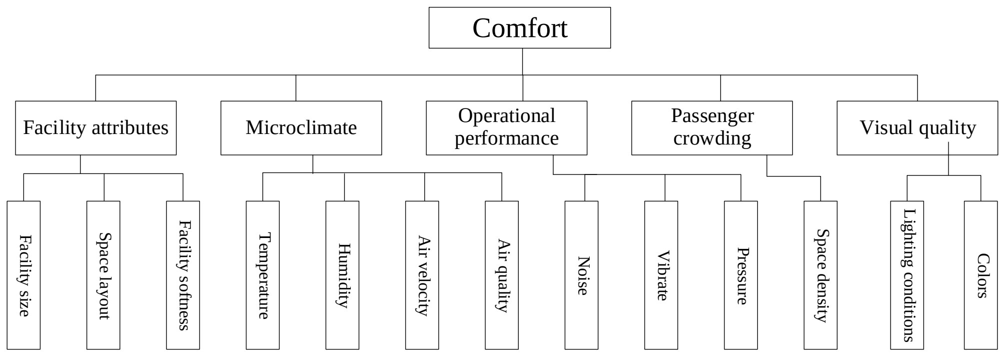

Fig 2: Subway train ride comfort index system

3.2 Comfort indicators in terms of visual quality

Visual quality is an evaluation of the environmental comfort inside and outside the train passenger compartment made by visual information through the visual system and the brain cognition, combined with previous personal experience. Visual quality depends mainly on the lighting conditions that meet the visual performance of passengers, the environmental viewing quality experience outside the train passenger compartment, and the color perception inside and outside the passenger compartment (e.g. Figure 3).

3.2.1 Lighting conditions

(1) Illuminance and illuminance uniformity

Horizontal illumination generally refers to the visual performance of the illumination of the work surface in terms of meeting the work task. In subway train passenger compartments, passengers have behaviors such as reading, and in order to meet the visual performance in this behavior, there are regulations on illumination and uniformity in the relevant standards. For example, the Chinese standard GB/T 7928-2003 "General technical specification for metro vehicles" stipulates that the average value of illuminance at a height of 0.8m from the floor surface is not less than 200lx, and the lowest value is not less than 150lx [38]. In contrast, the European standard EN 13272-1: 2019 "Railway applications - Electrical lighting for rolling stock in public transport systems" [39] recommends a minimum illumination level of 150 lux in the seating area, which is used to satisfy the reading needs of passengers; the minimum illumination level for safety is 75 lux.

In addition to horizontal illumination, vertical illumination also determines the overall space brightness of the subway passenger compartment and affects the comfort of passengers. Also, due to the use of electronic screens (e.g. route map screens, etc.), vertical illumination can affect passengers' search for station information. In addition, vertical illumination is more relevant to human non-visual needs [40], so vertical illumination becomes an important indicator of visual quality in the passenger compartments of subway trains. In an office environment, Ariës' study found that a vertical illuminance of 1,000 to 2,000 lux in the eye area is preferable [41], while in rail train passenger compartments, the vertical illuminance value domain is not clearly defined in the literature.

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(2) Absolute luminance, luminance ratio and glare

The preference for absolute luminance values and the preference for luminance ratios depend on the distribution of light and the adaptation of the eye. There is no limit to the brightness value in the standard of subway train passenger compartment.

Glare has been used to assess the visual comfort of light environments. When subway trains are running on the ground, they face the problem of day glare in clear weather conditions. In daylight environment evaluation, there are usually two glare indicators: daily glare index (DGI) and daily glare probability (DGP), and DGP is superior to DGI [42].
When a subway train runs under the ground, the train passenger compartment is mainly electrically illuminated. The brightness of the light source has a direct impact on passengers at this time and can be measured by Unified Glare Rating (URG). The International Commission on Illumination defines the calculation of UGR in the standard CIE 117-1995 [43].

$$UGR = 8\log\left[\frac{0.25}{L_b} \cdot \sum \frac{L^2 w}{p^2}\right] \tag{2}$$

where L_b represents the background luminance; L represents the luminance of the light source; ω represents the stereo angle of the light source; P represents the Guth Position Index of the light source. The URG is not greater than 22 [39].

3.2.2 Colors

Colors in the environment are associated with emotions and affect human mood and health [44, 45]. In the subway train passenger compartment environment, colors also affect the mood and health of passengers. Most subway trains run under the ground, mainly with electric light sources, so the passenger compartment environment has two kinds of colors: light sources and related facilities.

The light source color is quantified in terms of correlated color temperature (CCT) [46]. In the passenger compartment environment, the light source has an impact on passengers' ability to identify the color of related facilities in the compartment (e.g., seat surface color, etc.). The essence is that the relevant wavelengths in the light source spectrum are reflected by the surface of the object and enter the eyes of passengers, thus presenting colors that match the human senses. The indicator that describes the ability to render the color of an object well in an illuminated environment is the color rendering index (Ra) [46]. According to EN 13272 - 1: 2019 "Railway applications - Electrical lighting for rolling stock in public transport systems", the color temperature should not be higher than 5,000 K and the color rendering index should not be less than 80 [39].

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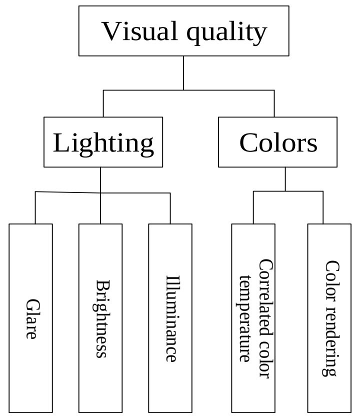

Fig 3: Comfort indicators in terms of visual quality

IV. Conclusion

It is significant to enhance the comfort of passengers riding in the passenger compartments of subway trains. This paper analyzes the characteristics of passenger behavior and the characteristics of the indoor and outdoor environment of subway train compartments, and builds a subway train ride comfort index system by using the analysis model of rail transportation influencing factors and combining with the index selection principles.

The ride comfort index system is built from five aspects: facility attributes, microclimate environment, operational performance, passenger crowding and visual quality. Our follow-up work will verify the validity, reasonableness and feasibility of the evaluation index system. The ride comfort level will be rated by measuring index weights and building evaluation models. We will select fully automated driverless subway trains in Beijing, Shanghai, and Chengdu as application cases to measure and evaluate the ride comfort of passenger compartment environment.

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