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Interactive Relationship Between Light Environment and Crowd Flow in Metro Station Concourses

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Abstract: This study takes Chongqing Nanping Metro Station as the research object, focusing on the collaborative optimization of light environment and crowd flow in metro station concourses. It aims to reveal the two-way coupling interaction mechanism between light environment and crowd flow, solve the mismatch between traditional static lighting design and the spatiotemporal heterogeneity of dynamic passenger flow, and achieve the dual goals of improving light environment quality and optimizing crowd flow efficiency. By integrating high-precision spectral measurement, AI video analysis, physiological signal monitoring and multi-agent simulation technology, a coupling database containing 2400 light environment parameters and 2600 dynamic passenger flow data is constructed. Random forest algorithm is used to identify illuminance, lighting uniformity and color temperature as key influencing factors. A quantitative model relating these factors to passenger flow speed, dwell time and path deviation rate is established based on partial least squares regression. The social force model is innovatively improved by introducing a visual perception correction coefficient, and a multi-agent coupling model is developed for verification. The results show that the optimal parameter combination is illuminance of 150–250 lx, color temperature of 4000–4500 K, and uniformity $U_0 \geq 0.6$, which can achieve a passenger comfort score of 4.1, a 15% increase in crowd flow speed, and a 25% reduction in lighting energy consumption. This study reveals the quantitative relationship between the two, providing important theoretical and methodological support for the refined design of metro spaces.

Keywords: Metro station concourse; Light environment; Crowd flow dynamics; Multi-agent simulation; Visual perception correction; Quantitative analysis

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1. Introduction

Against the background of smart city construction and rapid development of urban rail transit, by the end of 2024, the operating mileage of metro in China has exceeded 10,000 kilometers, and the Chongqing metro network covers more than 300 kilometers. Hub stations such as Nanping have a daily passenger flow of over 80,000, making metro the core artery of urban transportation. As the core hub for passenger distribution, transfer and ticket purchase, the station concourse differs from the static waiting platform with characteristics of high passenger density, fast movement speed and complex behavior types. Its light environment not only affects passenger comfort but also directly acts on crowd flow efficiency and spatial operation safety, and their coupling relationship is more complex than that of the platform.

Under the strategies of "dual-carbon" and the development of green construction and intelligent buildings, the intelligent design of light environment in metro stations is not only the key to improving passenger experience but also an important path to achieve energy saving and digital upgrading in the rail transit field. Traditional static lighting design cannot adapt to dynamic passenger flow, resulting in lighting energy waste and low operation efficiency. Existing studies mostly focus on the one-way impact of platform light environment on passenger comfort, lacking research on the two-way coupling between concourse light environment and crowd flow. Therefore, this study takes Chongqing Nanping Metro Station as a case to systematically reveal the interaction mechanism between light environment and crowd flow in metro station concourses through multi-source data fusion, machine learning modeling and multi-agent simulation, determine the optimal light environment parameter combination, provide technical solutions for intelligent design and green transformation of metro space light environment, and support the intelligent upgrading of urban rail transit [1].

2. Research methods

2.1. Research site

The concourse of Chongqing Nanping Metro Station is selected as the empirical object. It is a transfer hub of Rail Transit Line 3 and Line 10, with a total construction area of 2800 m² and a daily passenger flow of over 80,000. It has both commuter and leisure passenger flow characteristics with significant dynamic differences. The station concourse has clear functional zones, including 6 entrances, a ticket area with 8 ticket vending machines and 2 manual windows, 6 security check channels and 2 transfer channels.

2.2. Multi-source data collection

A five-dimensional data collection system of light environment, passenger flow, physiology, energy consumption and subjectivity is constructed. Data collection is carried out with high-precision equipment and standardized methods to ensure the multi-dimensionality, accuracy and representativeness of data. All equipment is strictly calibrated, and outliers are eliminated by the 3σ principle in data processing [2]. See **Table 1**.

Table 1. Multi-source data collection scheme

Data category	Acquisition equipment / methods	Core indicators	Sampling accuracy / frequency
Light environment parameters	Minolta CS-200 Spectroradiometer, OHSP-350 Spectral color illuminance meter	Illuminance, Correlated color temperature, CCT, Color rendering Index, CRI, Lighting uniformity, Unified glare rating, UGR, Illuminance gradient (Illuminance difference in light-dark transition zones)	Illuminance accuracy ± 4%, CCT Accuracy ± 100 K, 180 Grid measurement points, Synchronous collection in three periods: morning, noon, evening, and by functional zones, Realizing spatiotemporal matching between light environment and pedestrian flow data
Pedestrian dynamic data	Hikvision intelligent counter, Python OpenCV + YOLOv5/ DeepSORT, Wi-Fi probe	Passenger flow, Crowd density, Moving speed, Movement trajectory, Dwell time	AI counting accuracy ≥ 98%, Trajectory sampling rate 1 Hz, Dwell time error ≤ 10 s
Physiological response data	BIOPAC MP150 physiological signal acquisition system	Heart rate, HR, Heart rate variability, HRV, Galvanic skin response, GSR	Sampling frequency 1000 Hz, 50 Subjects aged 18–60 years
Lighting energy consumption data	Smart electricity meter, Lamp power detector	Lamp power, Real-time Power consumption, Lighting energy consumption coefficient	Accuracy ± 1%，Synchronous Sampling with light environment parameters
Subjective evaluation data	Structured questionnaire	Visual perception-behavioral decision preference, comfort score, Glare perception	400 questionnaires distributed, 352 valid responses recovered, Effective response rate 88%; Sample composition consistent with actual passenger flow

2.3. Data analysis and modeling

2.3.1. Identification of key influencing factors

A random forest model is built based on the Python scikit-learn library. Light environment parameters are taken as features and dynamic passenger flow indicators as labels. Model parameters are optimized through 10-fold cross-validation to avoid overfitting. Permutation importance test is used to verify feature importance. The results show that illuminance (0.32), lighting uniformity (0.28) and color temperature (0.25) are core influencing factors, while unified glare rating (0.12) and color rendering index (0.08) have weak effects and are excluded for simplified modeling.

2.3.2. Quantitative relationship modeling

Aiming at the multicollinearity between key factors and behavioral indicators, partial least squares regression is adopted to establish a quantitative model. The core quantitative relationships are finally obtained.

(1) Illuminance and passenger flow speed are significantly positively correlated in the range of 150–250 lx.

(2) Dwell time is the shortest at 4000–4500 K color temperature.

(3) When uniformity ≥ 0.6, the path deviation rate is lower than 5%.

A reverse threshold model of passenger flow indicators for light environment design requirements is constructed to clarify the light environment parameter requirements under different passenger flow characteristics.

2.3.3. Construction of multi-agent coupling model

The classic social force model ignores the influence of the light environment on visual perception. This study innovatively introduces the visual perception correction coefficient K_v and the passenger flow feedback correction coefficient K_f, and the improved social force model formula is as follows [2].

$$F_{total} = F_{desired} + F_{repulsive} + F_{attractive} + K_v + K_f$$

Where F_{total} denotes the total force, $F_{desired}$ is the desired motion force, $F_{repulsive}$ represents the repulsive force including interactions between pedestrian–pedestrian and pedestrian–obstacle, $F_{attractive}$ stands for the attractive force indicating the tendency to move toward the target point, is the visual perception correction coefficient, and K_f is the crowd flow feedback correction coefficient that reflects the reverse adjustment demand of light environment parameters according to crowd density and speed.

The visual perception correction coefficient is calculated by weighting the key light environment parameters. It works synergistically with the crowd flow feedback correction coefficient to realize the bidirectional coupling simulation: the positive influence of the light environment on crowd flow and the reverse feedback of crowd flow to the light environment. The specific formula is as follows:

$$K_v = \alpha \times \frac{E}{E_0} + \beta \times \frac{T_0}{T} + \gamma \times U_0$$

Where E is the measured illuminance, and E_0 is set to 200 lx as the optimal reference illuminance; T is the measured color temperature, and T_0 is set to 4250 K as the optimal reference color temperature; U_0 is the measured uniformity. The weight coefficients are optimized by the genetic algorithm, with $\alpha = 0.4$, $\beta = 0.3$, and $\gamma = 0.3$. The optimization objective is to minimize the error between the measured and predicted speed.

Formula of the newly added crowd flow feedback correction coefficient:

$$K_f = \delta \times \frac{\rho}{\rho_0} + \varepsilon \times \frac{v}{v_0}$$

Where ρ is the measured crowd density, and $\rho_0 = 2.5$ persons/m^2 is taken as the baseline crowd density for the station concourse; v is the measured crowd speed, and $v_0 = 1.2$ m/s is taken as the baseline crowd speed. The weight coefficients $\delta = 0.5$ and $\varepsilon = 0.5$ are optimized via the genetic algorithm, with the optimization objective being the collaborative adaptation between light environment parameters and crowd flow conditions.

Four types of agents, namely light environment agent, pedestrian agent, physiological response agent, and energy consumption agent, are constructed on the AnyLogic platform to realize collaborative simulation of light environment–crowd flow–physiology–energy consumption.

(1) The light environment agent simulates the spatial distribution of parameters and supports real-time adjustment.

(2) The pedestrian agent is endowed with attributes such as age and travel purpose, and simulates path selection and speed adjustment based on the improved social force model.

(3) The physiological response agent predicts heart rate variability and galvanic skin response, and feeds the results back to the pedestrian agent.

(4) The energy consumption agent collects real-time data of lamp power and regional power consumption, dynamically calculates the lighting energy consumption coefficient combined with light environment parameters and crowd density, and feeds back to the light environment agent synchronously to support energy-saving adaptive decisions for parameter adjustment.

Model verification is carried out by comparing measured data with simulation results. The errors of speed, dwell time and path deviation rate are controlled within 10%, which ensures the validity of the model.

3. Results and analysis

3.1. Current characteristics of light environment and crowd flow in the concourse

3.1.1. Problems of current light environment

The measured data indicate that the light environment in the concourse of Nanping Metro Station has four major core mismatches, which fall significantly short of the requirements for green and intelligent design.

(1) Mismatch between function and parameters

The illuminance in the security check area during the morning peak is 142 ± 32 lx, far below the national standard requirement of 300 lx, with a unified glare rating of 20 ± 0.8. The color temperature in the waiting area at night is 4980 ± 210 K, while 76% of passengers prefer warm light at 3800–4200 K. The uniformity of the transfer channel is 0.48 ± 0.03, and the illuminance gradient in the light–dark transition zone reaches 120 lx/m, which becomes a key cause of pedestrian flow stagnation. The illuminance gradient at nodes such as security check areas and ticket gates reaches 80 lx/m, leading to prolonged visual adaptation time for passengers and a reduction of more than 10% in ticket verification and gate passage efficiency.

(2) Mismatch between time period and demand

The illuminance in security check areas and transfer channels during the morning peak is not intensively adjusted, conflicting with peak passenger flow demand. The color temperature in the waiting area at night is higher than that during the morning peak, contrary to the warm light demand of leisure passengers. Glare complaints during the morning peak account for 65%.

(3) Mismatch between groups and perception

85% of passengers over 50 years old prefer low color temperature of 3800–4000 K at night, while young people aged 18–30 have a high acceptance of medium–high color temperature at 4500–4800 K. However, the station does not provide differentiated lighting.

3.1.2. Spatiotemporal characteristics of crowd flow

The crowd flow in the concourse of Nanping Metro Station presents significant spatiotemporal heterogeneity, forming an obvious contradiction between supply and demand with the current light environment.

(1) Spatiotemporal distribution

The total passenger flow during the morning peak (7:00–9:00) is 28,000 person-times, and the density of the transfer channel reaches 4.2 persons/m^2, characterized by high density and high speed. During the off-peak period (13:00–15:00), the total passenger flow is 12,000 person-times with a density of 1.5–1.8 persons/m^2. At night (21:00–23:00), the total passenger flow is 9,000 person-times, and the dwell time in the waiting area is 15.2 minutes, showing long dwell and low speed characteristics.

(2) Movement speed

The speed in the middle section of the transfer channel during the morning peak is 1.2 m/s, dropping to 0.84 m/s in the light–dark transition zone (a 30% decrease). The queuing speed in the security check area during the morning peak is only 0.3 m/s, increasing to 1.1 m/s after passing through. The speed at the entrance during the morning peak is 1.5 m/s, the highest among all periods.

(3) Group behavior

Passengers over 50 years old move at 0.8–1.0 m/s with visual adaptation time prolonged by 1.2 seconds per person. Passengers aged 18–30 move at 1.3–1.5 m/s. 92% of commuter passengers choose the shortest path, while 45% of leisure passengers walk around shops with longer dwell time.

3.2. Influence law of light environment parameters on crowd flow

(1) Illuminance

There is a significant positive correlation with passenger flow speed in 150–250 lx. Beyond this range, efficiency decreases due to insufficient vision or glare.

(2) Color temperature

4000–4500 K brings the highest passage efficiency. High color temperature at night increases fatigue, and there are obvious group differences.

(3) Lighting uniformity

Uniformity ≥ 0.6 ensures low path deviation rate and smooth passage. Transfer channels require higher uniformity.

(4) Illuminance gradient

It is a key inducement of crowd stagnation. The optimal threshold is ≤ 50 lx/m.

3.3. Verification of optimal light environment parameter combination

Three control groups (current group, optimization group 1, optimization group 2) were set up using the multi-agent coupling model to verify the optimization effect of light environment parameters. The simulation results during the morning peak are shown in **Table 2**.

Table 2. Simulation analysis results of the multi-agent coupling model

Group	Illuminance in security check area	Nighttime color temperature in waiting area	Uniformity in transfer channel	Congestion probability in security check area	Transfer channel efficiency	Comfort score	Heart rate variability
Current Group	142 lx	5000 K	0.48	35%	65 people/min	2.8	39 ms
Optimization group 1	200–250 lx	5000 K	0.6	15%	80 people/min	3.55	52 ms
Optimization group 2	150–250 lx	4000–4500 K	≥ 0.6	15%	80 people/min	4.1	58 ms

The experimental results show that the optimal parameter combination is illuminance of 150–250 lx, color temperature of 4000–4500 K, and lighting uniformity ≥ 0.6, achieving both excellent comfort and efficiency. The passenger comfort score reaches 4.1, and crowd flow speed increases by 15%. Deviation of any factor from the optimal range will lead to performance degradation. For example, when illuminance is 200 lx and color temperature is 5000 K, the comfort score drops to 3.2. However, considering the complexity of multiple functional zones in a metro station concourse, differentiated parameters should be adapted according to the passenger flow characteristics of each zone. The optimal parameter system for each functional zone is shown in Table 3.

Table 3. Optimal parameter system by functional zone

Functional zone	Passenger flow characteristics	Illuminance (lx)	Color temperature (K)	Lighting uniformity	Illuminance gradient (lx/m)	Congestion probability	Node passage efficiency	Comfort score
Security check area	High speed & high density	Morning peak: 200–250Off-peak/Evening peak: 150–200	4500	≥ 0.7	≤ 50	≤ 15%	≥ 85 people/min	4.0
Transfer channel	High speed & high density	Morning peak: 200–250Off-peak/Evening peak: 150–200	4000–4500	≥ 0.7	≤ 50	≤ 10%	≥ 90 people/min	4.1
Ticketing area	Medium speed & medium density	150–200	4000–4500	≥ 0.6	≤ 60	≤ 8%	≥ 30 people/min	4.2
Waiting area	Low speed & long dwell	150–200	3800–4000	≥ 0.6	≤ 60	≤ 5%	/	4.3
Elderly passenger area	Low speed & slow movement	150–200	3800–4000	≥ 0.7	≤ 50	≤ 5%	≥ 20 people/min	4.4

3.4. Accuracy analysis of the improved model

When the measured data were input into the improved social force model, the speed prediction error decreased from 15% in the classic model to 8%, and the path selection accuracy increased from 75% to 88%. The improved four-dimensional coupling model achieved a lighting energy consumption prediction error of ≤ 7%, enabling accurate prediction of energy consumption reduction under different parameter combinations and providing reliable support for energy-saving optimization.

Taking the light–dark transition zone of the transfer channel as an example, where the illuminance is 120 lx and uniformity is 0.45, the model predicts a speed of 0.82 m/s (measured: 0.84 m/s, error 2.4%) and a path deviation rate of 24% (measured: 25%, error 4%). It can accurately reproduce the two-way interaction process: light environment parameter optimization → crowd flow efficiency improvement and crowd density change → on-demand adjustment of light environment parameters. Compared with the traditional one-way model, the simulation fitting degree is increased by 20%, providing a reliable simulation tool for the design and optimization of metro light environments.

4. Discussion

This study advances the interactive research of light environment and crowd flow from qualitative description to quantitative analysis. It differs from existing platform research in spatial scope, research perspective and method. The core finding is the two-way coupling interaction mechanism, and the multi-agent coupling model provides a reliable digital tool. The traditional static design is incompatible with dynamic passenger demand, and the dynamic dimming strategy can improve efficiency and save energy. The study has limitations in individual factors and sample scope, which need further expansion and verification.

5. Conclusion and engineering application suggestions

5.1. Main conclusions

There are four mismatches between the light environment and crowd flow demand in Nanping Metro Station concourse. Illuminance, uniformity, color temperature and illuminance gradient are core factors with clear threshold effects. A two-way coupling mechanism exists between light environment and crowd flow. The improved multi-agent coupling model has high simulation accuracy. The differentiated parameter system achieves multi-objective optimization of comfort, efficiency and energy saving.

5.2. Engineering application suggestions

(1) Adopt an intelligent dynamic dimming system to realize time- and zone-based adjustment.
(2) Implement differentiated lighting design for different functional zones and groups.
(3) Optimize lighting layout to reduce glare and control illuminance gradient.
(4) Build an intelligent monitoring and evaluation system for light environment.
(5) Construct a four-dimensional intelligent regulation platform integrating monitoring, identification, feedback and metering.

Disclosure statement

The author declares no conflict of interest.

References

[1] Yang X, 2017, Research on Dynamic Characteristics and Evacuation of Pedestrian Flow in Metro Hub Station Based on Social Force Model, thesis, Beijing Jiaotong University.

[2] Zhang S, 2024, Research on Light Environment Demand of Metro Platform Based on Passenger Comfort, thesis, Shijiazhuang Tiedao University.

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