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MODELING OF PUBLIC PERCEPTION IN METRO-LED UNDERGROUND PUBLIC SPACE FOR PLANNING OPTIMIZATION: A CASE STUDY OF HONG KONG

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Abstract: Metro-led underground public spaces (MUPS) have become integral components of modern urban environments, particularly in high-density cities. However, their enclosed nature and artificial characteristics present various challenges affecting user experience and well-being. While traditional surveys and questionnaires have provided valuable insights into public perception of these spaces, such methods are often resource-intensive and limited in scale. This study proposes an innovative framework for evaluating public perception in MUPS by leveraging social media data and Large Language Model (LLM) technology. We developed a six-dimensional perception indicator system termed "FEPICS" (Functionality, Engagement, Pleasurability, Inclusiveness, Comfort, and Safety), encompassing 37 distinct indicators. Using Google Maps review data from eight metro stations along Hong Kong's Tsuen Wan Line, we employed LLM-based classification methods to extract and quantify public perception information, achieving a semantic recognition accuracy of 91,4%. Our analysis revealed that the "Functionality" dimension received the highest public attention, while "Inclusiveness" and "Comfort" garnered relatively less focus. The indicator "transfer" demonstrated the highest positive perception value, whereas "crowd congestion" exhibited the strongest negative sentiment. Through our perception evaluation index, we identified Jordan and Tsim Sha Tsui stations as best performers, attributable to their superior environmental design elements despite high crowding levels. These findings highlight the importance of balancing functional efficiency with environmental quality in MUPS design. The proposed FEPICS framework and LLM-based methodology offer a systematic approach for understanding and quantifying public perception in underground spaces, contributing to evidence-based planning practices. This study demonstrates the potential of integrating social media analytics with advanced language models for urban perception research, while providing practical insights for optimizing underground public space development.

Keywords: metro-led underground public space, social media data, public perception, large language model

1. INTRODUCTION

Metro-led underground public spaces, encompassing transportation hubs, pedestrian networks, retail areas, and other facilities within metro systems, have become integral to modern urban environments (Bobylev, 2016, Dong et al, 2021). These spaces address land scarcity and growing transportation demands in high-density cities while serving as dynamic venues for shaping urban experiences (Ma et al, 2023, Liu et al, 2024, Shao et al, 2024). They play a crucial role in enhancing spatial vitality and improving regional livability (Dong et al, 2023). However, their enclosed nature and artificial environmental characteristics challenges such as crowding perception, insufficient spatial orientation, and thermal imbalances, directly impacting user experience and well-being

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(Jasińska and Kłosek-Kozłowska, 2024). These challenges underscore the need for a comprehensive understanding of public perception.

Recent years have witnessed growing scholarly attention to public perception of underground spaces. Jalón et al. (2019) employed face-to-face surveys to collect multi-dimensional perception preference data regarding spatial quality, temperature, cleanliness, and seating facilities from diverse occupational groups using metro and bus systems. Liu et al. (2025) gathered safety perception dimensions of metro imagery through volunteer-based safety scoring. Zeng et al. (2025) utilized on-site questionnaires to collect public perception data on physical environment and satisfaction levels in underground complexes. While these studies provide valuable public perspective insights for optimizing multifunctional underground spaces, traditional data collection methods, though robust, are time and resource-intensive. The widespread application of social media data has introduced new possibilities for studying public perception. Su et al. (2025) proposed a machine learning-assisted text mining approach to transform unstructured social media reviews into structured urban behavioral insights. Guo et al. (2025) employed geo-tagged social media data to characterize public perception hotspots and their spatial distribution patterns. Yin et al. (2024) conducted sentiment analysis on COVID-19 vaccination-related tweets using OpenAI's large language models to explain the geographical distribution of emotional gradients. However, attempts to utilize social media data for underground space public perception mining remain limited. While Pan et al. (2025) proposed a method integrating social media and academic literature data to model public cognition knowledge graphs for underground public spaces, current research lacks a systematic quantitative evaluation framework that can directly guide planning practices.

To address these research gaps, this study aims to establish a perception evaluation framework tailored to metro-led underground public spaces and develop a quantitative modeling method for public perception using social media data and LLM technology. Specifically, this research addresses the following questions:

(1) What are the key dimensions of perception in metro-led underground public spaces?

(2) How can LLM technology extract and quantify perception information from social media data?

(3) How can the quantitative model of public perception inform underground public space planning?

The remainder of this paper is structured as follows: **Section 2** outlines the methodology, including the development of the “FEPICS” perception indicator system and the LLM-based framework for public perception modeling. **Section 3** presents the results of quantitative analyses and evaluations of metro-led underground public spaces. **Section 4** discusses the implications of the findings for planning practices and identifies methodological limitations. Finally, **Section 5** summarizes the main contributions of this research.

2. MATERIAL AND METHODS

2.1. Research framework

Our study uses review data from the Google Maps platform as the data source. Google Maps is one of the most widely used digital mapping services, with a broad user base and a comprehensive geographical information database in Hong Kong, including location information for subway stations and a significant amount of user reviews. Additionally, Google Maps provides diverse data APIs, making it convenient to structure public comments using NLP techniques and Python.

We collected over 3.000 user reviews from eight subway stations in Hong Kong. From this initial dataset, we utilized NLP techniques to intelligently clean many meaningless or blank invalid comments. Building on previous research, we innovatively proposed a six-dimensional conceptual model, which includes “Functionality”, “Engagement”, “Pleasurability”, “Inclusiveness”, “Comfort”, and “Safety” (FEPICS). This model was expanded to include a perception indicator system for metro-led underground public spaces, comprising 37 indicators.

Based on the aforementioned data and theoretical foundation, we employed LLMs to structurally model public perception information for the eight subway stations. Subsequently, we defined and quantitatively analyzed the public perception heat and preferences, proposing a perception index value and an underground public space perception evaluation index based on this analysis. The framework of this method is illustrated in **Figure 1**.

2.2. Study area and data preparation

This study focuses on the Tsuen Wan Line in the Hong Kong Special Administrative Region, selecting eight representative subway stations for in-depth research (**Figure 2**). As a leading global metropolis with high density, Hong Kong has a subway system that has developed over more than 50 years, making its underground public spaces significant for research and reference. The Tsuen Wan Line, Hong Kong's first cross-sea railway, was completed in 1982 and serves as a crucial transportation artery connecting the Kowloon Peninsula and Hong Kong

Island. The line spans 16,9 kilometers and has 16 stations, with an average daily ridership of 944.100 (Hong Kong Legislative Council).

The selected representative stations along the Tsuen Wan Line are: Sham Shui Po, Prince Edward, Mong Kok, Yau Ma Tei, Jordan, Tsim Sha Tsui, Admiralty, and Central. These stations cover two core areas: Kowloon (from Sham Shui Po to Tsim Sha Tsui) and Hong Kong Island (Admiralty and Central), both of which experience extremely high passenger density. Additionally, the study sites encompass various urban typologies, including traditional retail areas (Mong Kok), modern business districts (Admiralty and Central), residential neighborhoods (Sham Shui Po and Prince Edward), tourist hotspots (Tsim Sha Tsui), and mixed-use areas (Yau Ma Tei and Jordan). These locations have been developed over different periods and exhibit significant variations in population density, commercial characteristics, and development patterns, adding substantial research value. These differences may impact the public's experience and perception of underground public spaces. Therefore, comparative research on these stations will help reveal the differing public perception characteristics of various types of underground public spaces, providing valuable insights for future planning and optimization.

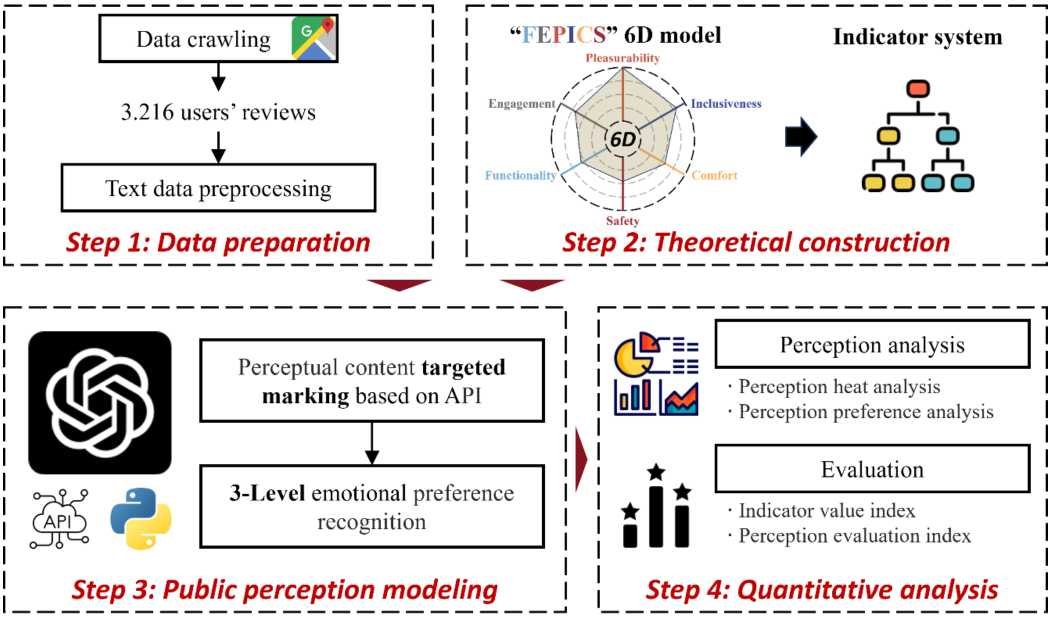

Figure 1. *Methodological framework*

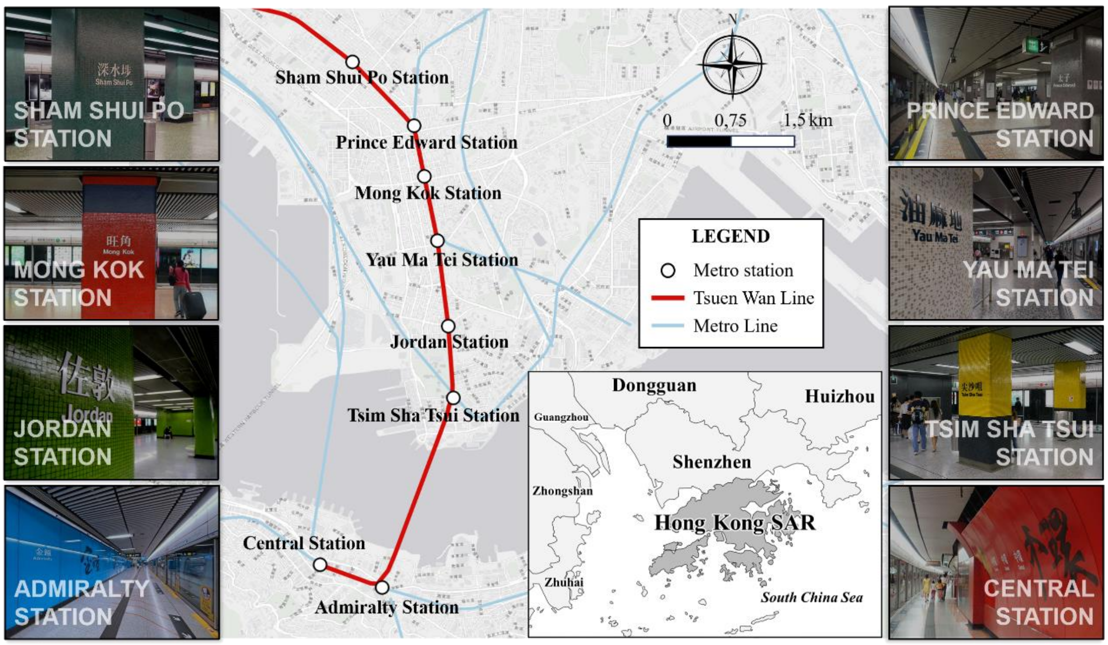

Figure 2. *Methodological framework*

We utilized the API provided by Google Maps (https://www.google.com.hk/maps/) to scrape all review data for the eight subway stations mentioned above, resulting in a total of 3.216 entries. Each review contains: [user ID, user rating star level, user review]. After applying NLP techniques to automatically filter out comments that were meaningless or blank, we obtained a total of 1.429 valid reviews. The number of valid reviews for each subway station is shown in **Table 1**.

Table 1. *The volume of valid reviews for each metro station*

Station	Sham Shui Po	Prince Edward	Mong Kok	Yau Ma Tei	Jordan	Tsim Sha Tsui	Admiralty	Central
num	216	62	267	127	114	218	209	216

2.3. Indicator system for public perception of MUPS

2.3.1. "FEPICS" perception model

Based on Mehta's (2014) five-dimensional model of public spaces ("Inclusiveness", "Meaningful Activities", "Safety", "Comfort", "Pleasurability"), this study develops a six-dimensional perception model termed "FEPICS," which includes "Functionality", "Engagement", "Pleasurability", "Inclusiveness", "Comfort", and "Safety".

Firstly, the significance of spatial functionality in planning and design research necessitates the inclusion of the "Functionality" dimension, particularly given the transportation-centric nature of subway stations. Furthermore, this study reinterprets the "Meaningful Activities" dimension from Mehta's model as "Engagement" to more accurately capture the interaction between individuals and underground public spaces. The "FEPICS" model retains Mehta's dimensions of "Pleasurability", "Inclusiveness", "Comfort", and "Safety", while revising the elements within each dimension to better reflect the characteristics of underground public spaces in subway stations. This adaptation enhances the model's relevance and applicability, providing a comprehensive framework for evaluating public perception in these unique environments.

2.3.2. Indicator system for perception of MUPS

Building on previous research on public and underground spaces, we have innovatively developed a six-dimensional perception indicator system for underground public spaces, termed "FEPICS". This comprehensive framework encompasses 37 distinct indicators, as illustrated in **Table 2**.

2.4. Quantitative modeling for public perception of MUPS

2.4.1. Public perception modeling

People's comments on different subway stations carry their perceived imagery and perceived conception. To better visualize and quantify public perception imagery, we refer to the public perception indicator system (see **Table 2**). Additionally, we categorize the perception context into three emotional tendencies, namely "positive", "neutral", and "negative".

We designed a targeted classification extraction method for perceived imagery based on ChatGPT API technology (see **Figure 3**). Using Python to call the API, we carefully crafted prompts to input the review text data from various subway stations, allowing the LLM to automatically identify and extract perceived imagery corresponding to the indicators in **Table 2**. Furthermore, we determined emotional tendencies based on the user ratings associated with each comment (1-2 stars: negative; 3 stars: neutral; 4-5 stars: positive). We selected 100 reviews for manual classification and verification, finding that ChatGPT achieved a semantic recognition accuracy of 91,4% within the classification framework established for this study.

We stored the extracted perception content for the various subway stations using a multivalued dictionary data structure. In this structure, the 37 indicators serve as keys, while the extracted perceived imagery and perceived conception are stored in separate imagery and conception dictionaries, with perceived imagery and emotional scores as their respective values. We systematically processed the review data for the eight subway stations in Hong Kong, establishing quantitative models of public perception for each station. This approach allows for a structured analysis of the perceived attributes associated with each station, facilitating a deeper understanding of how different factors influence public sentiment and experience in metro-led underground public spaces.

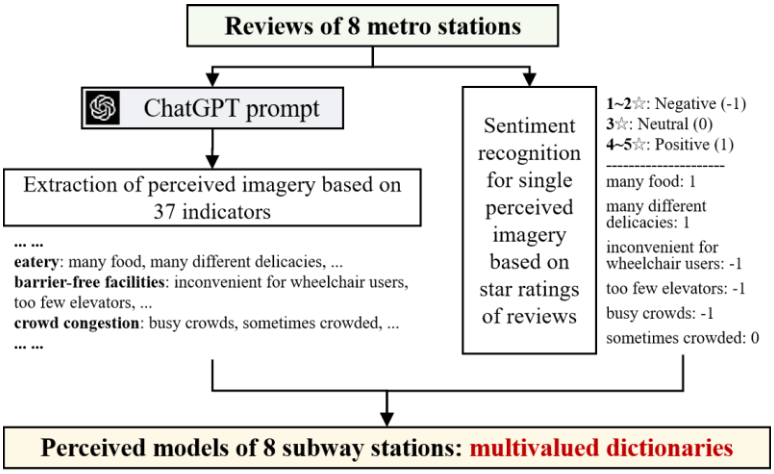

Figure 3. *Public perception modeling workflow*

2.4.2. Quantitative analysis of perception

Firstly, to measure the public's perception heat for different dimensions and indicators, we define the perception frequency PF_{ij}. Here, $i = 1, \cdots, 37$, represents the 37 perception indicators, and $j = 1, \cdots, 8$, refers to the eight subway stations. PF_{ij} represents the count of perception content corresponding to the i indicator in the comment data for the j subway station. The weight calculation is shown in Equation (1):

$$w_i = \frac{\sum_{j=1}^{8} PF_{ij}}{\sum_{i=1}^{37} \sum_{j=1}^{8} PF_{ij}} \quad (1)$$

Secondly, based on the perception conception dictionary, we define the perception emotional preference index PP. Its calculation is presented in Equations (2) and (3):

$$PP_{ij} = \frac{1 * n_{ij+} + 0 * n_{ij0} + (-1) * n_{ij-}}{n_{ij+} + n_{ij0} + n_{ij-}} \quad (2)$$

$$PP_i = \sum_{j=1}^{8} \frac{N_j}{N} PP_{ij} \quad (3)$$

Here, n_{ij+} represents the count of positive perception content for the i indicator at the j subway station, n_{ij0} denotes the count of neutral perception content for the i indicator at the j subway station, and n_{ij-} indicates the count of negative perception content for the i indicator at the j subway station. N_j represents the total number of valid comments for the$j$ subway station, with N set to 1.429, reflecting the total number of valid comments across these 8 subway stations.

2.4.3. Quantitative evaluation of metro-led underground public spaces

To comprehensively evaluate the public perception of metro-led underground public spaces, we define the value index of perception indicators VP_i. Its calculation is presented in Equation (4):

$$VP_i = PP_i * w_i \quad (4)$$

Based on this, we further define the perception evaluation index of the subway station EP_j, with its calculation shown in Equation (5):

$$EP_j = \sum_{i=1}^{37} PP_{ij} * VP_i \quad (5)$$

3. RESULTS

3.1. Analysis of indicator system

We calculated the weights for each indicator according to Equation (1), and the results are presented in **Table 2**. It is evident that the public is most concerned about the “Functionality” dimension, while there is comparatively less attention given to “Inclusiveness” and “Comfort”.

Table 2. *“FEPICS“ perception indicator system*

Dimensions	Perceptions	Indicators	weight_I	weight_D
Functionality	signage system clarity	signage and wayfinding system	0,038	0,325
	restroom needs	sanitation facilities	0,078	
	barrier-free design	barrier-free facilities	0,020	
	traffic efficiency	walking experience	0,027	
		transfer	0,162	
Engagement	social activity	popularity	0,081	0,218
	dining attraction	convenience store	0,003	
		eatery	0,055	
	other functions	customer service	0,023	
		ticket vending machine	0,001	
		other forms of activities	0,056	
Pleasurability	unique imagery design	wall decoration	0,004	0,182
		advertisement	0	
		landmark	0,001	
	visual appeal	lighting design	0,006	
		color scheme	0,001	
		environment design & planning	0,031	
	openness and connectivity	accessibility and connectivity	0,063	
		vertical connectivity	0,009	
		visual openness	0,068	
Inclusiveness	entrance and exit convenience	entrance/exit system	0,032	0,032
	opening hours	opening hours	0	
Comfort	sufficiency of rest seats	resting seat	0,003	0,021
	thermal comfort	air conditioner	0,011	
		ventilation	0,004	
	acoustic comfort	noise	0,003	
		soundproofing	0	
Safety	surveillance coverage	CCTV cameras	0,001	0,221
		security monitor	0	
	security trustworthiness	security guard	0,015	
		emergency response	0,001	
	traffic risks	equipment malfunction	0,008	
		crowd congestion	0,197	
		falls, collisions and trampling	0	
	disaster prevention and risk management	emergency exit	0	
		fire extinguisher	0	
		alarm system	0	

Subsequently, we computed the perception preference index PP_i and the perception value index VP_i for each indicator, with the results illustrated in **Figure 4**.

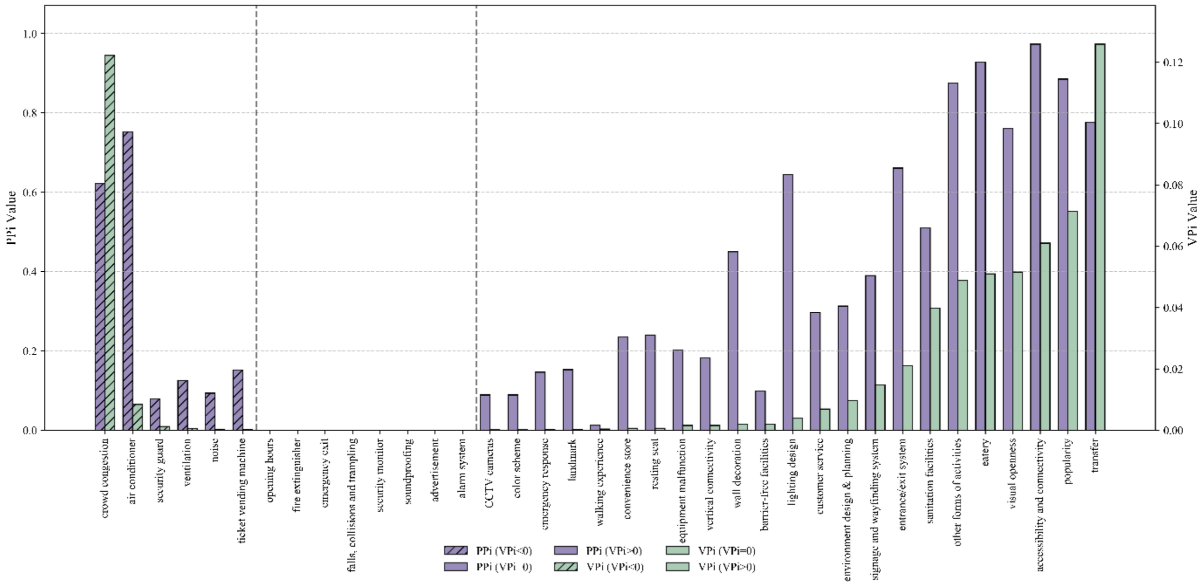

Figure 4. Perception preference index (PP_i) and value index (VP_i) of indicators

From **Figure 4**, we can observe that the indicator with the highest positive VP_i is "transfer", while "crowd congestion" exhibits the greatest negative VP_i. Furthermore, indicators such as "opening hours" and "fire extinguisher" have a zero VP_i.

3.2. Modeling for public perception of metro-led underground public spaces

We further illustrated the perception distribution across the eight subway stations in Hong Kong. The perception heat is depicted in **Figure 5**, while the perception preferences are shown in **Figure 6**.

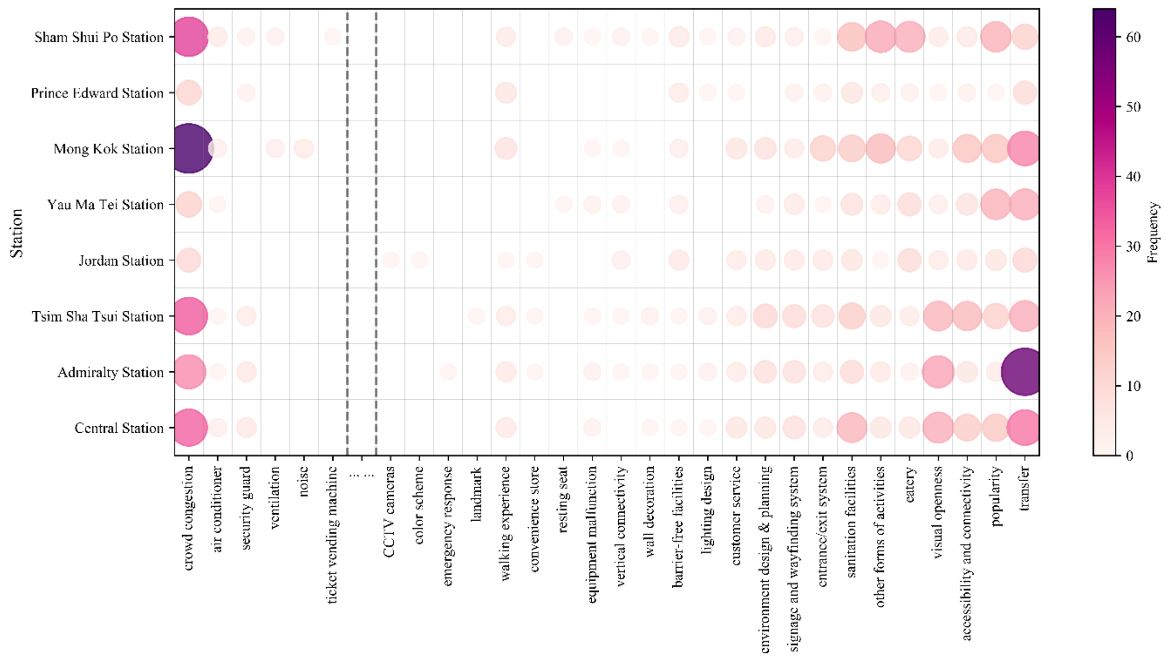

Figure 5. Perception frequency

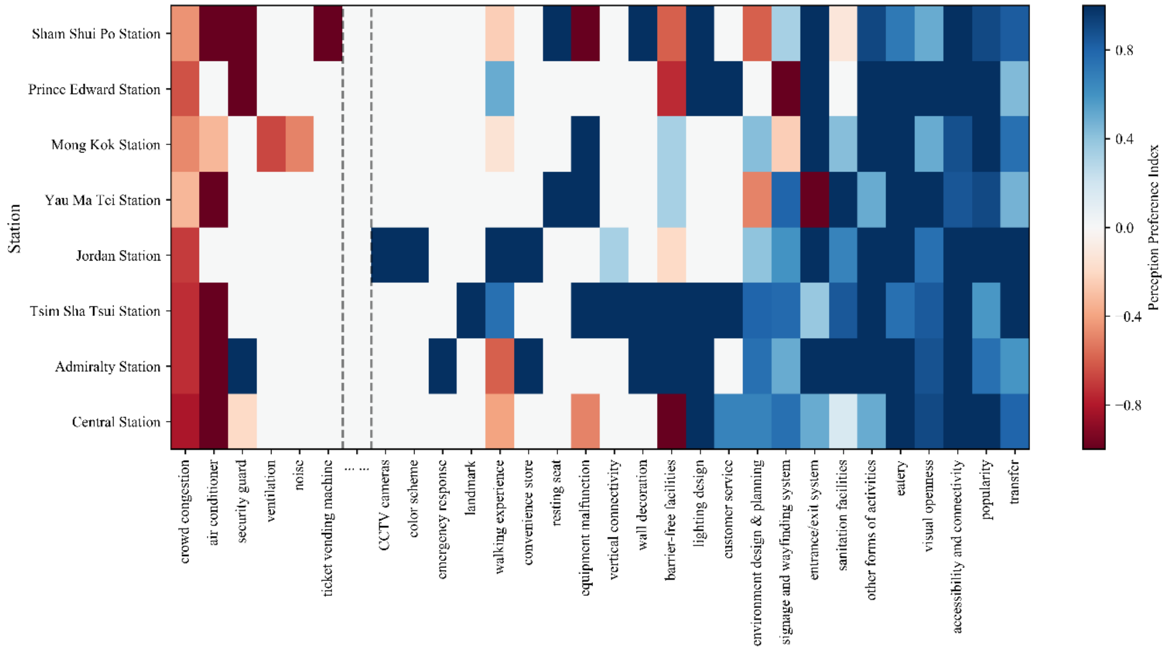

Figure 6. *Perception preference*

We omitted certain indicators with a zero VP_i to reduce blank spaces in the figures. It is evident that "crowd congestion" has the highest perception heat at Mong Kok Station, with a negative sentiment. In contrast, "transfer" has the highest perception heat at Admiralty Station, accompanied by a positive sentiment.

3.3. Evaluation of perceived metro-led underground public spaces

We evaluated the eight metro-led underground public spaces in Hong Kong using the perception evaluation index EP_j, with the results presented in **Table 3**:

Table 3. *"FEPICS" perception indicator system*

Station	Sham Shui Po	Prince Edward	Mong Kok	Yau Ma Tei	Jordan	Tsim Sha Tsui	Admiralty	Central
EP	0,420	0,434	0,448	0,381	0,544	0,536	0,514	0,504

Among them, Jordan Station and Tsim Sha Tsui Station received the highest EP_j, while Yau Ma Tei Station had the lowest.

4. DISCUSSION

4.1. Insights from perception quantification results for underground public space planning

Through the analysis of Google Maps review text data for eight popular metro-led underground public spaces along the Tsuen Wan Line in Hong Kong, we observed that the public exhibits notable enthusiasm for certain indicators, such as "transfer" and "crowd congestion". However, the emotional attitudes towards these two indicators differ significantly. From **Figure 6**, it is evident that all subway stations have a positive sentiment towards "transfer", while "crowd congestion" is associated with negative sentiment. This indicates that the public is relatively satisfied with the transfer functionality at these eight subway stations, aligning with the initial objectives of underground public space development. Conversely, the indicators with negative sentiment highlight existing issues in the utilization of metro-led underground public spaces. To further examine these issues, we selected the perception content corresponding to the indicators “crowd congestion” and “air conditioner” for a word cloud representation, as shown in **Figure 7**.

“crowd congestion” **“air conditioner”**

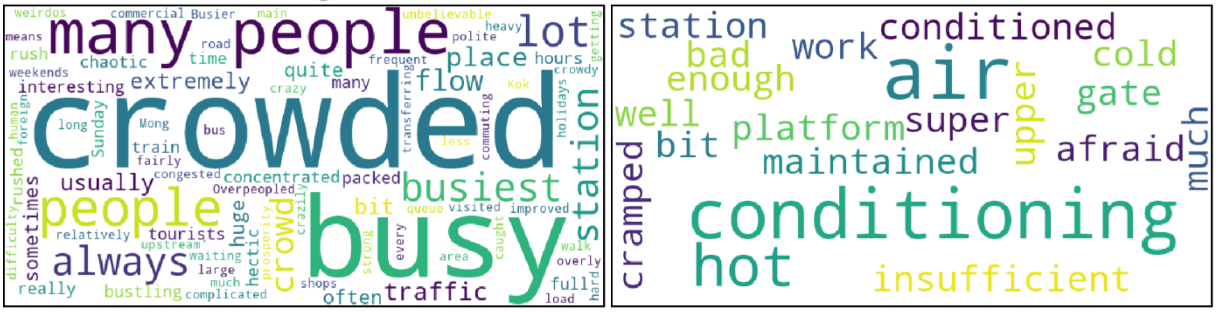

Figure 7. *Word clouds of “crowd congestion“ and “air conditioner“*

From **Figure 7**, it can be inferred that the issues of crowd density and uneven air conditioning in the metro-led underground public spaces of Hong Kong are commonly disliked by the public. Additionally, considerations regarding security and ventilation facilities should be enhanced.

Our findings suggest specific spatial and technical solutions for improving underground public spaces. For instance, the negative perception of “crowd congestion” at Mong Kok Station could be addressed through redesigning circulation paths, optimizing entrance/exit placement, and implementing smart crowd management systems. The positive perception of environmental design elements at Jordan and Tsim Sha Tsui stations - particularly their effective use of color schemes and landmarks - provides concrete examples for future planning. These stations demonstrate how thoughtful interior design, including appropriate lighting levels, clear sight lines, and distinctive architectural features, can enhance user experience despite high passenger volumes.

Indicators with a zero VP_i seem to indicate blind spots in public perception. These indicators are primarily concentrated in the “Safety” dimension. Therefore, as planners and managers, it is crucial to ensure low risk in the “Safety” dimension and to consider increasing public awareness and education regarding this aspect.

In comparing the eight subway stations, we designed a perception evaluation index (EP_j). Analyzing the higher-scored Jordan Station and Tsim Sha Tsui Station against the lowest-scored Yau Ma Tei Station reveals that, despite the former receiving more public complaints about “crowd congestion”, they excel in indicators related to “environment design & planning”, “color scheme”, and “landmark”, which are associated with the “Pleasurability” dimension. This may suggest that the interior environmental design of underground public spaces is crucial for enhancing public experience.

4.2. Limitations and prospects

While our study presents a novel approach to analyzing public perception of metro-led underground public spaces using LLMs, several limitations should be acknowledged. The reliance on Google Maps reviews as a single data source introduces inherent sampling biases, potentially underrepresenting certain social groups such as elderly citizens, low-income individuals, and those less familiar with digital platforms. Additionally, our analysis does not account for temporal variations in the review data, which may obscure important patterns in public perception across different times of day, seasons, or significant events. From a methodological perspective, the current framework does not consider the potential interdependencies between different perception indicators, limiting our understanding of how various aspects of underground spaces interact to shape the overall public experience.

Despite these limitations, this study introduces an innovative perception evaluation framework for metro-led underground public spaces and proposes a novel method for extracting and modeling public perception from social media data. The proposed “FEPICS” indicator system could serve as a foundation for developing comprehensive assessment tools across different urban contexts. Future studies could validate and refine these indicators through comparative analyses, potentially revealing how perception priorities differ across social and cultural settings. The adaptability of this framework also enables its extension to other types of underground spaces, such as commercial complexes or cultural facilities, contributing to a more systematic understanding of underground space perception.

The methodology developed for extracting and quantifying public perception using LLMs and social media data demonstrates considerable potential for advancing urban studies. This approach could be adapted to analyze various urban spaces and phenomena beyond underground environments, offering new possibilities for understanding public experience. The quantitative modeling approach could be integrated with other urban data analytics tools, enabling more sophisticated analyses of the relationship between spatial characteristics and public perception. Furthermore, this method's capacity for processing large-scale, real-time data could support more responsive and evidence-based urban planning practices, particularly in the context of smart city development.

5. CONCLUSION

This study developed an innovative framework for evaluating public perception of metro-led underground public spaces through the integration of social media analytics and LLM technology. By developing the six-dimensional "FEPICS" perception indicator system and constructing a corresponding quantitative modeling framework, we systematically analyzed Google Maps reviews from eight metro stations along Hong Kong's Tsuen Wan Line. This analysis identified key factors influencing public perception and their implications for urban planning, offering valuable insights into how different dimensions shape user experiences in underground spaces. Our methodology not only addresses the growing need for evidence-based underground space evaluation but also provides a replicable framework for understanding and quantifying public perception in complex urban environments. Specifically, our research demonstrates the following:

(1) The development of the FEPICS perception evaluation framework, which expands upon Mehta's five-dimensional model by incorporating "Functionality" and reinterpreting "Meaningful Activities" as "Engagement", provides a comprehensive system for evaluating public perception in metro-led underground spaces. This six-dimensional framework, encompassing 37 distinct indicators, offers a nuanced understanding of public perception across functional and experiential dimensions.

(2) Our LLM-based perception modeling approach, combining ChatGPT API technology with targeted classification extraction methods, achieved a semantic recognition accuracy of 91,4%, demonstrating the effectiveness of automated perception analysis from social media data. This methodological innovation enables efficient and scalable analysis of public sentiment in underground spaces.

(3) Quantitative analysis revealed significant variations in perception across different dimensions and stations. The "Functionality" dimension received the highest attention (weight = 0,325), with "transfer" emerging as the most positively perceived indicator. Conversely, "crowd congestion" exhibited the strongest negative perception, highlighting critical areas for improvement in underground space management.

(4) Station-specific evaluation identified Jordan and Tsim Sha Tsui stations as best performers, attributable to their superior environmental design elements despite high crowding levels. This finding underscores the importance of balanced development addressing both functional efficiency and environmental quality.

While our study provides valuable insights for underground space planning optimization, we acknowledge limitations in data source diversity and temporal coverage. Future research should explore multiple data sources and integrate temporal analysis to capture more comprehensive perception patterns. Additionally, investigating the interdependencies between perception indicators could enhance our understanding of how different aspects of underground spaces interact to shape overall public experience. Despite these limitations, our FEPICS framework and LLM-based methodology offer a robust foundation for evidence-based planning and design of metro-led underground public spaces, contributing to more user-centric urban development.

6. ACKNOWLEDGMENTS

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