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RESEARCH ARTICLE

IPA Analysis and optimization of pedestrian environment at railway stations in Guangdong-Hong Kong and Macao: An example of six typical stations

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ABSTRACT

Due to the increasing urbanization and growing regional integration, the Guangdong-Hong Kong-Macao Greater Bay Area is progressively transforming into a globally recognized metropolitan cluster. Rail transit is an effective and eco-friendly kind of public transport that plays a crucial role in fostering regional economic connections and facilitating people's movement. It has become the primary option for inhabitants when it comes to travelling. This study examines the influence of the walking environment's quality on passenger travel experience (the overall satisfaction and comfort felt by passengers when walking in a rail station area), station attractiveness (the degree of attractiveness of a rail station to passengers, which is usually determined by a combination of a number of factors, such as accessibility, safety, and interest of the station area) , and the overall livability of the city (the overall quality of life that a rail station area provides to Residents, including the quality of the environment, infrastructure, public services) . It does so by analyzing the walking environments of six representative rail transit stations in the Guangdong-Hong Kong-Macao Greater Bay Area, using the Walking Demand Hierarchy Theory as a basis. The study employed the IPA model to evaluate 20 crucial characteristics of the pedestrian environment. The findings revealed variations in the performance of different stations with regard to accessibility, safety, identification, functionality, and enjoyment. The differences provide a reference point for further optimizing the pedestrian environment in the Greater Bay Area rail station areas.

Keywords: IPA; GBA; railway station area; pedestrian environment

1. Introduction

The Greater Bay Area (GBA) of Guangdong-Hong Kong and Macao is located on the southern coast of China and covers nine cities in Guangdong Province (Guangzhou, Shenzhen, Zhuhai, Foshan, Dongguan, Zhongshan, Jiangmen, Zhaoqing and Huizhou) together with the Hong Kong and Macao Special Administrative Regions (SARs), totalling around 56,000 square kilometres. Geographically situated on both banks of the Pearl River Estuary, with the South China Sea to the east and adjacent Southeast Asia, this area is strategically positioned as a crucial entry point linking mainland China with the global community (**Figure 1**).

The GBA holds a crucial role in China's national economic landscape as a significant gateway for

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regional development and international engagement. The Guangdong, Hong Kong, and Macao Greater Bay Area have been undergoing rapid growth in recent years, transforming into a globally renowned city cluster due to the increasing pace of urbanisation and the deepening of regional integration. Rail transit, emerging as the predominant form of public transport in the Greater Bay Area, offers efficiency and environmental sustainability, significantly enhancing economic connectivity and facilitating the movement of people both within and between cities in the region. This phenomenon not only enhances the strong interconnections among the cities in the region, but also establishes a solid basis for the sustained progress of the Greater Bay Area.

Figure 1. Map of Guangdong-Hong Kong and Macao Guangdong-Hong Kong and Macao (Source: CGTN).

With the swift growth of rail networks, the condition of pedestrian environments at stations has increasingly become a crucial determinant of passenger travel experience, the appeal of train stations, and the general liveliness and sustainability of cities. Liveability refers to the capacity of a city or community to effectively offer its residents with high-quality living conditions. This often includes the presence of safe, healthy, and easily accessible infrastructure, social services, and environmental conditions[15]. An optimal pedestrian environment not only improves the ease and quality of travel for passengers, but also boosts the use of public transit, therefore contributing to the reduction of traffic congestion, decrease in carbon emissions, and promotion of healthy lives[2,3]. Consequently, the enhancement of the pedestrian environment in station areas is crucial not only for enhancing the overall efficiency of urban transport systems, but also for advancing sustainable urban growth. Sustainability pertains to the capacity to fulfil the requirements of the current generation without jeopardising the capacity of future generations to fulfil its own requirements, highlighting the equilibrium between safeguarding the environment, social accountability, and economic feasibility[4-6].

The impact of a high-quality pedestrian environment on the ease and comfort of commuters during arrival and departure from a train station significantly affects inclination to use public transport. Simultaneously, the quality of the pedestrian environment is also in connection to the effectiveness of the whole urban transport system. This is because well-developed pedestrian links can decrease the dependence on private vehicles, alleviate traffic congestion and environmental pollution, so improving the overall liveability and sustainability of the city[157]. Hence, the scientific and rational optimisation of the pedestrian environment in rail transit station areas to improve service quality and attractiveness has emerged as a crucial concern in the present urban planning and traffic management of the Guangdong-Hong Kong-Macao Greater Bay Area. This will directly contribute to enhancing the travel experience of residents.

2. Literature review

The pedestrian environment in the rail transit station area has gained significant attention due to the ongoing expansion of the urban transport system and the increasing diversity of people's travel requirements. The elements of the walking environment typically encompass the accessibility of amenities, the security of the area, the pleasantness of the surroundings, and the comprehensibility of signage[8]. Thus, these features are commonly acknowledged as fundamental markers for assessing the quality of the pedestrian environment[9]. Accessibility of facilities pertains to the ease with which pedestrians can utilise the paths and amenities. Spatial safety concerns the sense of security and protection experienced by pedestrians, encompassing factors like traffic safety and crime prevention. Environmental comfort primarily encompasses the width of the walking paths, the presence of greenery, and the level of noise. Signage clarity ensures that pedestrians can effortlessly navigate to intended destinations. The interaction of these elements dictates the overall excellence of the pedestrian surroundings, which subsequently impacts the effectiveness of the train station and the general satisfaction of the passengers' journey.

The quality of the walking environment is influenced by various elements, which can be classified into three primary categories: the physical environment, the social environment, and institutional considerations. The physical environment encompasses the tangible surroundings where pedestrians traverse, encompassing elements such as road layout, pedestrian amenities, and landscaping. Reasonable road design may effectively guarantee the safety and comfort of pedestrians, while well-designed walking amenities such as sidewalks, benches, and lighting can offer convenience to pedestrians. Furthermore, sufficient vegetation not only enhances the visual enjoyment of pedestrians but also diminishes the degree of noise and air pollution in the nearby surroundings, significantly contributing to the comfort of walking. Leow (2008) presents precise methods for enhancing the pedestrian environments at MRT interchanges and in the Central Business District (CBD) in Singapore. Specifically, Leow conducted an analysis in the central business district (CBD) region to examine the movement of pedestrians across underpasses and flyovers during busy periods. The study demonstrated that enhancing the lighting, ventilation, and signage systems of these passages can greatly improve the overall pedestrian experience. Furthermore, he emphasised the need of maximising the pedestrian walkways surrounding the metro stations and minimising the interference caused by traffic to improve the whole travel experience[10].

Mak and Koh (2021) also examined comparable instances of enhancing pedestrian environments in cities located in East Asia. The authors highlight that in Hong Kong, the implementation of pedestrianised zones and the enhancement of public transport links have successfully increased the convenience and safety of pedestrian travel, resulting in a more conducive living environment for city dwellers. Study demonstrates that a conducive walking environment not only encourages the use of public transit, but also substantially mitigates traffic congestion and air pollution, therefore fostering sustainable urban growth[11].

The social environment primarily focuses on the social elements that impact the behaviour of pedestrians, including population density, perception of social safety, and community cohesion[12]. High population density can result in crowded walking spaces, but it can also increase the liveliness and perception of safety while walking. Conversely, lower population density can lead to a lack of warmth in the walking area, which can impact the sense of safety for pedestrians. Moreover, enhancing community policing and lowering crime rates can effectively foster a heightened perception of social safety, thereby instilling a greater sense of comfort among pedestrians.

In research on transport and station building evaluation, Li et al. (2019) employed a multi-objective optimisation model to optimise the placement of metro stations in order to achieve a balance between accessibility and cost-effectiveness[13].The mixed-integer linear programming technique developed by Chen and Zhang (2020) enhanced passenger movement and comfort at high-speed rail stations[14]. In study, Wang et al. (2018) used a simulation model and a genetic algorithm to enhance the management of passenger flow at stations and mitigate congestion during periods of high demand[15]. In contrast, Some scholars employed a Geographic Information System (GIS)-based multi-objective optimisation model to enhance the sustainability of bus network geometry[16]. The aforementioned studies demonstrate the utility of optimisation models in enhancing the efficiency of transport system and station design.

A significant amount of literature emphasises that by further enhancing the walking environment, it is feasible to greatly improve the travel experience for pedestrians by enhancing and adjusting all elements of the urban walking environment to ensure that walking is safer, more comfortable, convenient, and efficient. Forsyth and Southworth (2008) emphasised the need of enhancing pedestrian facilities, improving safety, enhancing environmental quality, and upgrading signage systems. Experimental evidence has demonstrated the efficacy of these approaches in improving the pedestrian experience and, consequently, the overall quality of the walking environment.

Alfonzo (2005) introduced a hierarchical model of walking needs, highlighting the importance of addressing the fundamental safety, comfort, and pleasure requirements of walkers in order to establish a walking environment of superior quality[16]. Ewing and Cervero (2010) demonstrated in the research that enlarging the width of footpaths, decreasing the volume of motorised traffic, and incorporating greenery and street furniture can greatly enhance the appeal of a walking environment. Substantially improve the appeal of the pedestrian environment. Furthermore, the study conducted by Loukaitou-Sideris and Eck (2007) investigated the potential of community involvement and collaborative design in augmenting the happiness of the walking experience by means of enhancing the cultural and social significance of walking settings[16].

This includes the use of advanced technologies like big data and IoT to dynamically monitor and regulate pedestrian activity[16]. In the study, Shen et al. (2018) examined a smart walking system that utilises IoT technology to dynamically optimise walking routes and facility layouts by monitoring pedestrian traffic and environmental factors in real-time[20]. This system aims to improve the efficient and safe walking environments. Gehl (2011) underscored the significance of human-centred urban design, proposing that the general quality of the walking environment should be improved by implementing micro urban design techniques, such as incorporating user-friendly seating, public artwork along walking routes, and barrier-free design strategies[21]. Real-time monitoring of pedestrian movement has been implemented in Shenzhen, located in the Guangdong-Hong Kong-Macao Greater Bay Area. This application of intelligent transport systems aims to improve the safety and convenience of the walking environment by optimising traffic signals and walking paths[22]. Concurrently, Guangzhou is actively advocating for intelligent lighting and monitoring systems that not only conserve energy, but also adapt lighting levels in real-time based on sensor data to suit varying walking requirements during the day and improve nighttime safety[23].

Scholars have undertaken several empirical studies on walking settings using various methodologies, including questionnaire surveys, behavioural observation, and geographical analysis. The IPA analysis approach is a valuable tool for evaluating and improving walking environments because it takes into account the significance of elements and the level of performance[1624]. This method allows for the identification of essential characteristics that should be given priority for improvement in the walking environment. As a result, it provides a scientific foundation for the development of optimisation strategies[25].

Previous research has extensively examined the components, influencing factors, and optimisation strategies of pedestrian environments. However, there is a notable absence of systematic research on the pedestrian environment in rail transit station areas within the specific regional context of the Guangdong-Hong Kong-Macao Greater Bay Area. This paper aims to propose practical optimisation strategies for pedestrian environments at rail transit stations in the Guangdong-Hong Kong-Macao Greater Bay Area. The strategies are based on in-depth empirical analysis and are tailored to the unique needs and challenges of these environments. The goal is to address the gaps in current research and provide a scientific basis for optimising the landscape design of urban pedestrian spaces in the region.

3. Research design

3.1. IPA model

IPA (Importance-Performance Analysis) is a strategic tool used for decision-making. It takes into account the variations between users' psychological expectations (perceived significance) and present perceptions of the situation (perceived performance or happiness with the existing situation). An analysis of the perceived relevance and satisfaction of different functional elements of the walking environment around urban rail transit, represented in a two-dimensional matrix, would offer a more rigorous foundation for making strategic decisions aimed at enhancing satisfaction with the walking environment.

The IPA (Importance-Performance Analysis) model is a widely utilised analytical tool for evaluating and enhancing the quality of services or the performance of products. The methodology facilitates the identification of areas that want improvement and areas that exhibit satisfactory performance by comparing the user's perceived significance of a specific feature with level of satisfaction with the experience. The IPA model is typically illustrated with a two-dimensional matrix, where the vertical axis represents perceived importance and the horizontal axis represents satisfaction. The results indicate that the factors can be categorised into four quadrants: high importance-low satisfaction (focus on improvement), high importance-high satisfaction (maintain strengths), low importance-low satisfaction (give moderate attention), and low importance-high satisfaction (allocate moderate resources). This IPA analysis method can offer businesses or decision-makers precise guidance to attain optimal enhancement with constrained resources. Based on the findings of the IPA analysis, crucial factors that contribute to the improvement of the walking environment in the rail transit station areas of Guangdong, Hong Kong, and Macao. This identification enables the development of effective strategies aimed at enhancing the overall satisfaction of pedestrians in the urban pedestrian environments surrounding these rail transit stations.

3.2. Questionnaire design and data collection

3.2.1. Sample selection

The rail transport system in the Guangdong-Hong Kong-Macao Greater Bay Area has a broad reach, and the study focuses on six specific rail stations that are strategically located in the core cities of the Bay Area. These stations include important interchange hubs such as Guangzhou East Station, Shenzhen North Station, and Huizhou South Station, as well as commercial areas like Hong Kong's Central Station, Guangzhou's Huacheng Avenue Station, and Shenzhen's Laogai Station. The selection of these stations ensures an even distribution across the region. The samples are guaranteed to have comprehensive coverage and be representative.

3.2.2. Questionnaire design

This questionnaire is designed using the Hierarchy of demands theory and focuses on pedestrians' specific needs. It examines 20 environmental elements that impact various parts of urban rail stations. The elements were classified into five primary study dimensions: accessibility, safety, identity, functionality, and enjoyment of the rail station area. The precise research indicators can be found in **Table 1**.

Table 1. Assessment of environmental elements.

Category	Code	Evaluation factor
Accessibility	F1	Designing Walking Paths for Accessibility
	F2	Walking path maintenance
	F3	The presence of several transit options in the area surrounding the station
	F4	Operation of linear staircases both indoors and outdoors at the station
Security	F5	Pedestrian crossings and crossing facilities when crossing the street inside and outside the site
	F6	Illumination during the night inside the designated area
	F7	Peak hour pavement capacity Coordinating the timing of traffic lights with pedestrian signals
	F8	Coordinating the timing of traffic signals with pedestrian signals
Identifiability	F9	Signage within and outside the property is clear
	F10	Enhancing the legibility of directional and distance signage on pathways
	F11	Signage indicating the directions to different services and shops
Functionality	F12	Proportion of recreational and artistic establishments in the region
	F13	Provide shade amenities along pedestrian routes and designated waiting places
	F14	Evaluation of the sufficiency of sitting-out areas
	F15	The versatility of adjacent service facilities
	F16	Sanitary conditions of the public restrooms on the premises
Excitement	F17	Artworks or ornamental objects positioned alongside the pathways
	F18	Frequency of public events hosted in the pedestrian zone
	F19	Factors to Consider in Spatial Design for Year-Round
	F20	Encouragement is given for pedestrians to participate and stay in the designated pedestrian area

In order to collect the respondents' subjective evaluations of the significance of the assessment of variables that influence the walking environment, as well as current levels of contentment with regard to the evaluation, the questionnaire was developed. Using a Likert scale, the semantics of the phrases "very important/satisfied, important/satisfied, average, relatively unimportant/satisfied, and unimportant/satisfied" were described. To reflect these categories, scores of 5, 4, 3, 2, and 1 were awarded to each of the categories.

3.2.3. Data collection

In the study, the data were collected through a well-designed questionnaire, multiple channels, and a variety of methods to ensure the representativeness of the samples and the diversity of the data. This was done to collect information that was both comprehensive and accurate regarding the walking environment around the rail transit stations in Guangdong, Hong Kong, and Macao.

The process of distributing questionnaires involved the utilisation of both online and offline means in conjunction with one another. On the one hand, the questionnaire was made available online through the Questionnaire Star platform, making use of its extensive coverage and convenience in order to collect a large number of samples rapidly. On the other hand, members of the research team went out into the field, distributed paper questionnaires, and communicated directly with pedestrians in order to guarantee that the questionnaire was completed accurately. Not only does the use of a multi-channel questionnaire collection approach guarantee the comprehensiveness and representativeness of the data, but it also enhances the credibility and applicability of the conclusions of the research.

A total of 617 valid questionnaires were gathered after one month of collecting them. In addition to providing a reliable basis for further studies, the data from the questionnaire served as an efficient basis for conducting a comprehensive evaluation of the walking environment at each location. The selection of participants was based on user groups who had directly used the six locations being studied. This approach was used to maximise direct experience and comments regarding the pedestrian environment around the facilities. Participants should exhibit a wide range of usage frequency and travel incentives, encompassing various modes of travel such as commuting, leisure, and shopping, as well as individuals with varying usage frequencies, to represent the usage patterns of the sites accurately. Furthermore, the participants' socio-demographic data should encompass dimensions such as age, gender, occupational background, and place of residence to guarantee complete representativeness of the sample in these categories. Criteria formulation will mitigate bias caused by a homogeneous sample structure, therefore improving the generalisability and reliability of the study findings.

Regarding bias considerations, the study should prioritise addressing systematic biases that could arise throughout the process of collecting representative samples. Employing both online and offline questions can impact the selection of participants. For instance, online questionnaires are more likely to attract a younger and more Internet-savvy demographic, whereas offline surveys may target an older cohort with less frequent Internet usage. Integrating these two data-gathering techniques allows for partial compensation of these possible biases, leading to more accurate data and guaranteeing the broad relevance and reliability of the study's conclusions.

4. Analysis of data

4.1. Reliability and validity

Within the scope of this investigation, the validity and reliability of the questionnaire were subjected to a thorough examination in order to guarantee the precision and dependability of the results. When it comes to reliability, the internal consistency of the questionnaire was evaluated by calculating Cronbach's Alpha coefficient. The results of this calculation revealed that the Cronbach's Alpha coefficients of each dimension reached 0.971, which indicates that the questionnaire has a very high internal consistency. This suggests that the questionnaire reflects the respondents' perceptions of the walking environment accurately. When it comes to validity, the KMO value is 0.985, and the P-values of Bartlett's Spherical Test are all less than 0.001, which indicates that the questionnaire has a good level of validity.

4.2. Analysis of the station pedestrian environment

According to the pedestrian environment evaluation index system that was established earlier, six train stations in the GBA area were evaluated for pedestrian environment. Every entry in the table corresponds to the mathematical average of each station on a specific aspect of the evaluation, a systematic approach that accurately quantifies and contrasts the performance of several stations. The findings of the evaluation are presented in **Table 2** below.

Table 2. Evaluation results of walking environment perception at six metro stations in GBA.

Category	Code	Guangzhou East Station	Shenzhen North Station	Huizhou South Station	Huacheng Avenue Statio	Hong Kong Central Station	Shenzhen Laojie Station
Accessibility	F1	3.64	3.68	3.66	3.77	3.70	3.64
	F2	3.69	3.67	3.72	3.71	3.68	3.77
	F3	3.71	3.79	3.75	3.76	3.82	3.63

	F4	3.65	3.67	3.67	3.61	3.73	3.59
Security	F5	3.63	3.81	3.69	3.64	3.76	3.79
	F6	3.67	3.76	3.72	3.67	3.73	3.72
	F7	3.58	3.69	3.70	3.70	3.89	3.65
	F8	3.59	3.55	3.64	3.60	3.75	3.68
Identifiability	F9	3.60	3.59	3.67	3.78	3.73	3.71
	F10	3.61	3.54	3.69	3.74	3.71	3.83
	F11	3.60	3.58	3.66	3.81	3.75	3.67
Functionality	F12	3.73	3.64	3.73	3.68	3.90	3.66
	F13	3.63	3.74	3.69	3.69	3.73	3.66
	F14	3.51	3.49	3.58	3.63	3.57	3.64
	F15	3.61	3.68	3.65	3.75	3.60	3.57
	F16	3.63	3.55	3.62	3.61	3.71	3.67
Excitement	F17	3.67	3.40	3.67	3.73	3.64	3.80
	F18	3.60	3.62	3.65	3.57	3.76	3.74
	F19	3.62	3.54	3.68	3.65	3.95	3.74
	F20	3.77	3.49	3.68	3.65	3.65	3.85

The data shows that Flower City Avenue Station is the highest in terms of F1 rating (3.77), while Hong Kong Central Station performs best in terms of F3 rating (3.82). Overall, Shenzhen North Station also had higher accessibility ratings, especially for F3 (3.79). These results suggest that the continuity of walking paths and accessibility facilities vary significantly between stations, affecting the travelling experience of pedestrians.

When compared to the other stations, Hong Kong Central Station received a much higher F7 grade (3.89), which indicates that it has a higher level of social security and traffic safety than the other stations. In addition, Shenzhen North Station fared quite well on the F5 rating (3.81), with higher scores that were received overall. Based on these findings, nighttime lighting and pedestrian crossing facilities play a significant role in enhancing pedestrians' perceptions of safety, which in turn encourages more people to walk.

Another significant component that plays a role in how pedestrians perceive surroundings is the degree to which they are recognisable. Both Flower City Avenue Station and Hong Kong Central Station received higher scores, ranging from F9 to F11, suggesting that guide signs and environmental design were of a higher quality. Flower City Avenue Station had a stellar rating of 3.81 out of a possible 5. Shenzhen Old Street Station also performs well in terms of its F10 rating, which is 3.83. This indicates that stations with high recognition can provide a better experience for pedestrians in terms of navigation and orientation during experiences.

Hong Kong Central Station performs the best in terms of functionality, particularly with regard to the F12 rating (3.90), which is much better than the ratings of the other stations. In terms of F12 and F15 ratings, Flower City Avenue Station and Huizhou South Station both do exceptionally well. Stations that have a high level of functionality typically have better infrastructure and more convenient facilities, which is beneficial for walkers because it creates a more comfortable environment for walking.

In terms of interest, Hong Kong Central Station achieved the best in terms of F19 rating (3.95), which indicates that it is a more appealing and engaging environment for strolling. Also performing well on the F20 scale was Shenzhen Old Street Station, which had a score of 3.85. According to these numbers, a pedestrian environment that is rich in intriguing and appealing elements has the potential to increase the level of satisfaction experienced by pedestrians dramatically and to improve the entire experience of travelling substantially.

Taking everything into consideration, Hong Kong Central Station has the most significant total score, which indicates that it has the most favourable view of the environment designed for pedestrians. Shenzhen North Station received the lowest total score, while Shenzhen Laogai Station and Huacheng Avenue Station both scored higher than Shenzhen North Station. The disparities in the scores of the six sites on each dimension were statistically significant before the IPA analysis. The scoring discrepancies reveal the areas where some sites really perform well and where they lack proficiency in particular aspects. Requisite contextual information was given for the following IPA analyses to assess the significance and compare performance.

4.3. An examination of the relationship between satisfaction and its perceived importance

Table 3 presents the statistical findings about the perceived importance of the IPA questionnaire as well as the current level of satisfaction respondents have with it. The cumulative mean is calculated by summing the mean scores of all evaluation components and then dividing the sum by the total number of factors. It is estimated that the average overall perceived satisfaction is around 3.68, the average overall perceived importance is approximately 3.97, and the overall perceived importance is 0.29 points greater than the current satisfaction. The fact that there is still a particular gap between people's contentment with the current condition and the perceived importance of the aspects of the walking environment is something that can be observed. This gap suggests that the significance of the walking environment is high, while the satisfaction with the current situation is lower. On account of this, there is still potential for development in terms of people's contentment with the area surrounding the station that is conducive to walking.

Table 3. Analysis of satisfaction and perceived importance.

Code	The current level of satisfaction		Perceived importance	
	Average	Overall average	Average	Overall average
F1	3.68		3.97	
F2	3.71		4.01	
F3	3.74		4.02	
F4	3.65		4	
F5	3.72	3.68	4.03	3.97
F6	3.71		4.02	
F7	3.7		3.95	
F8	3.64		3.97	
F9	3.68		4	
F10	3.69		3.99	
F11	3.68		3.93	
F12	3.72		3.92	
F13	3.69		3.95	
F14	3.57		4.02	
F15	3.64		3.99	

Code	The current level of satisfaction		Perceived importance	
	Average	Overall average	Average	Overall average
F16	3.63		4.06	
F17	3.65		3.89	
F18	3.66		3.9	
F19	3.7		3.92	
F20	3.68		3.88	

The satisfaction and perceived importance scores shown in **Table 3** are crucial for constructing the IPA Matrix (Importance-Performance Analysis Matrix). This matrix can enable the identification of areas that require priority attention and improvement by comparing the perceived importance of each component with the existing satisfaction scores.

4.4. IPA matrix analysis

A matrix analysis using the IPA method was conducted to evaluate the perceived significance and present satisfaction levels of each element. The study utilised a horizontal axis to represent people's assessed happiness with different aspects of the pedestrian environment, while the vertical axis represented people's perceived importance. The quadrant demarcation point was determined by calculating the average of the two axes. The current state of the pedestrian environment around urban rail transit stations is determined by identifying the features present in each quadrant distribution. The elements are categorised into the crucial maintenance area, fundamental improvement area, general improvement area, and essential maintenance area. These factors function as the foundation for making decisions when proposing ideas for improvement.

Based on the IPA matrix analysis, it was found that seven out of the twenty elements of the walking environment fall under the maintenance improvement area (F1, F2, F3, F5, F6, F9, F10). Six elements are categorised under the critical improvement area (F7, F11, F12, F13, F19, F20). Two elements are in the stable improvement area (F17, F18), and five elements are in the maintenance status area (F4, F8, F14, F15, F16) (**Figure 2**).

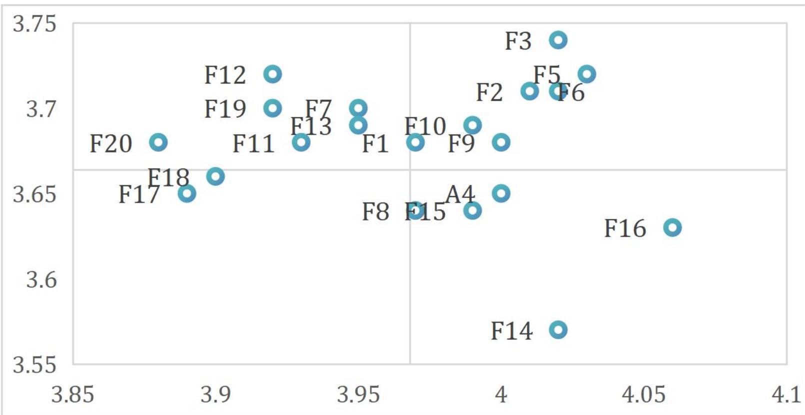

Figure 2. Analysis of IPA matrix.

4.4.1. Crucial maintenance areas

Quadrant I is specifically intended to uphold the area's condition and efficiency, and the features situated in this quadrant are seen as highly important and satisfying for walkers. The recommended approach is to uphold optimal conditions through regular maintenance consistently. The elements in this region consist of footpath levelling (F1), footpath maintenance (F2), and traffic interchange (F3) in the accessibility classification. In the safety classification, the elements comprise safety facilities (F5), illumination (F6), station signs (F9), and road walk signage (F10). The well-preserved walking paths around rail stations in certain old urban areas and commercial districts contribute significantly to this. While plant roots may damage some paths, most intersections have pedestrian crossings or overpasses. Additionally, the number of lighting facilities and illuminance level generally meet the demand for use and provide better facilities. The data indicates that as the building of train stations in the Greater Bay Area (GBA) continues to progress and improve, people have gained a more pragmatic and utilitarian awareness of the requirements of the surrounding pedestrian environment, resulting in relatively high levels of satisfaction.

4.4.2. Fundamental improvement area

Quadrant II is the specific area that requires significant improvement in terms of depth. The variables within this area are judged to have a lower degree of satisfaction and a higher level of relevance for pedestrians. The recommended approach is to concentrate on enhancing and perfecting, progressively advancing into Quadrant I. The factors present in this area are as follows: pavement width (F7) falls under the safety classification; signage for commercial and service facilities (F11) falls under the recognition classification; leisure and cultural venues (F12) and shade facilities for roads and waiting areas (F13) fall under the functional classification; and spatial design that considers seasonal variations (F19) and interactive design (F20) fall under the fun classification for six projects.

4.4.3. General improvement area

Quadrant III is an area where there is potential for substantial development. Elements in this zone are characterised by having relatively low perceived importance and contentment with the current situation for pedestrians. Nevertheless, the significance of components in this domain may progressively escalate as individuals' standard of living enhances. Thus, the appropriate approach is to consistently enhance and adjust to the evolving demands and degrees of happiness of individuals as circumstances permit. However, because it is considered to be of lesser significance, it is given a lower priority compared to Quadrant II. The area in question contains public artefacts (F17) and public events (F18) within the Interest Classification. This implies that there is an anticipation for streets to have a greater abundance of public artefacts in order to enhance the atmosphere. By augmenting the quantity of artefacts, it is possible to enhance people's contentment with the pedestrian environment.

4.4.4. Basic maintenance area

Quadrant IV represents a maintenance plan aimed at preserving fundamental levels of enjoyment. The elements in this area are considered to be of relatively low significance, and there is a high level of contentment with the current pedestrian situation. The equivalent approach is to uphold a significant degree of contentment. However, it is given less priority than Quadrant I due to its perceived significance being lower than that of Quadrant I. As the perceived significance grows, items in this domain may progressively shift towards ensuring precision. Based on the IPA matrix results, this area consists of five auxiliary access facilities (F4) for accessibility, traffic signals (F8) for safety, shade facilities (F14), service facilities (F15), and public toilets (F16) for functional classification. This implies that the factors present in this area can contribute to people's satisfaction with the walking environment by ensuring regular maintenance. Contentment.

5. Suggestions for improvement

5.1. Give priority to enhancing fundamental areas

The factors identified as fundamental improvement areas in the survey, such as pavement width, signage for commercial and service facilities, recreational and cultural venues, shade facilities for roads and waiting areas, consideration of seasonal changes in spatial design, and interactive design, are of high importance but have a low level of current satisfaction. These areas should be prioritised for improvement. Concrete actions are advised in the subsequent domains: i) Expand the width of sidewalks, particularly in areas with high pedestrian activity during busy periods, to improve the convenience and comfort of pedestrians passing through; ii) Implement more visible and user-friendly signage for commercial and service establishments both inside and outside the stations, to ensure that pedestrians can navigate effortlessly during journeys. iii) Enhance the quantity of recreational and artistic facilities along the pedestrian routes, including parks, open areas, and public art spaces, in order to establish a more appealing atmosphere, for instance, in the United States, the New York rail station area facilitates the expansion of pedestrian space and incorporates a diverse range of practical applications to encourage the development of multimodal, economically vibrant zones (**Figure 3**); iv) Enhance the pedestrian experience in waiting areas and walking paths by adding more shade facilities, ensuring comfort in various weather conditions; v) Take into account seasonal variations when designing walking areas, incorporating facilities and landscaping that can adapt to different seasons, thereby increasing the appeal throughout the year; vi) Foster engagement among pedestrians by incorporating interactive design elements in walking paths, such as interactive art installations or information display screens, to encourage participation and prolong stay, for instance, the public artwork displayed on Orchard Road in Singapore actively promotes the engagement and prolongation of pedestrian activity (**Figure 4**).

Figure 3. New York rail station pedestrian space

Figure 4. Orchard Road sculpture, Singapore

5.2. Sustain and improve current advantages

To ensure continued satisfaction with current factors such as barrier-free design of walking paths, road maintenance, transport interchange facilities, lighting facilities, and directional signs inside and outside stations, it is crucial to maintain and optimise them. Hence, it is advisable that: i) Conduct routine inspections and maintenance on barrier-free facilities, roads, and lighting systems to ensure optimal condition at all times; ii) Although the existing directional signs are functioning effectively, they should be regularly updated and improved to align with regional development and evolving pedestrian needs, ensuring accurate and user-friendly information guidance. For instance, the London, UK, guidance system update (**Figure 5**).

Figure 5. Guidance system update, London, UK.

5.3. Direct attention towards upcoming patterns and developments.

To address variables that presently have low relevance and satisfaction, such as public artworks and the frequency of public activities, it is advisable to remain adaptable and make modest, moderate enhancements based on future shifts in demand. In Barcelona, for example, the ' Super Neighborhoods ' project has increased the number of public artworks and community interactions, significantly enhancing the cultural atmosphere of the area and the satisfaction of Residents (**Figure 6**). i) Incrementally incorporate additional artworks and decorative elements into the pedestrian areas to augment the cultural ambience and artistic merit of the pedestrian environment; ii) Where circumstances allow, introduce more captivating public activities to enhance the interactive experience of the walking area and amplify the liveliness and allure of the vicinity.

Figure 6. Street rehabilitation in Barcelona.

6. Conclusion

The findings of this study suggest that the walking environment at rail transit stations in the Guangdong-Hong Kong-Macao Greater Bay Area significantly impacts the travel experience of passengers and the overall efficiency of the rail transit system. A thorough evaluation of the pedestrian environment at six representative rail transit stations in the Guangdong-Hong Kong-Macao Greater Bay Area was carried out using the IPA model analysis. Out of the total of 20 pedestrian environment factors, seven are situated in the Crucial Maintenance Area (CMA). This suggests that these factors are currently highly satisfactory and should be maintained in good condition to meet the pedestrians' needs. On the other hand, six factors are located in the Fundamental Improvement Area (FIA). This indicates that these factors are considered highly important, but the satisfaction level is low. Therefore, they require improvement. The two factors are situated within the General Improvement Zone, indicating that moderate enhancements should be implemented as circumstances allow. On the other hand, the five factors are located within the Basic Maintenance Area (BMA), where the present condition is generally satisfactory and only regular maintenance needs to be upheld.

The study's findings demonstrate the ranking of enhancements identified for several aspects of the pedestrian environment. The pedestrian environment elements in Quadrant I, which is a crucial maintenance area, have been highly rated in terms of satisfaction and perceived importance. This suggests that the current performance of the elements in this quadrant is rather satisfactory. It is crucial to maintain the existing levels of features in this quadrant in order to retain pedestrian satisfaction, especially in terms of pedestrian route maintenance, traffic transfers, and on-site and off-site signage. Elements in this quadrant suggest that certain places have already achieved a higher level of basic pedestrian amenities and information-oriented systems. However, it is important to continue maintaining this favourable status. Quadrant II represents the Fundamental Improvement Area (FIA), which encompasses elements that pedestrians deem highly important yet are currently unsatisfied with and require immediate repair. More precisely, these encompass factors such as the breadth of the pavement, the presence of signs for commercial and service establishments, the availability of recreational and cultural destinations, and the provision of shaded areas along the road. Enhancements to the factors above will significantly improve the entire pedestrian experience, particularly in terms of spatial and interactive design, hence making the site environment more appealing. Quadrant III represents areas that are currently of low relevance and satisfaction but are expected to become more critical as the quality of life improves. Thus, the elements in this quadrant need to be given priority for improvement. However, it is still essential to focus on development in the future. For example, enhancing the atmosphere of the pedestrian environment can be achieved by expanding the presence of public artefacts and organising more public events. Quadrant IV, known as the Basic Maintenance Area (BMA), consists of elements that are highly satisfying but could be more critical. Maintaining the existing level of maintenance for these elements is advised. This encompasses the administration of traffic signals and the fundamental operations of service facilities, among other things. The current condition of this quadrant component has mostly fulfilled the requirements of pedestrians, and the primary objective is to uphold regular maintenance to guarantee an ongoing degree of satisfaction.

In summary, the study highlights the disparities in the pedestrian infrastructure and emphasises the necessity for enhancements at various railway stations across the Guangdong-Hong Kong-Macao Greater Bay Area. An improved pedestrian infrastructure not only increases the appeal of rail transit and encourages more citizens to use public transport but also dramatically improves the overall sustainability of the city. The optimisation strategy for the pedestrian environment should consider accessibility, safety, identity, functionality, and enjoyment. This will improve the quality of service and attractiveness of rail transit stations in the Greater Bay Area, ultimately enhancing the travel experience for residents and the overall liveability of the city.

Declarations

Conflict of Interest

The authors declare no conflict of interest.

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The author(s) acknowledged that the manuscript submitted is his/her/ original work; all authors participated in the work substantively and are prepared to take public responsibility for the job; all authors have seen and approved the manuscript as submitted; the manuscript has not been published and is not being submitted or considered for publication elsewhere; the text, illustrations, and any other materials included in the manuscript do not infringe (plagiarism) upon any existing copyright or other rights of anyone. Notwithstanding the above, the Contributor(s) or, if applicable, the Contributor's Employer, retain(s) all proprietary rights other than copyright, such as Patent rights, to use, free of charge, all parts of this article for the author's future works in books, lectures, classroom teaching or oral presentations; the right to reproduce the article for purposes provided the copies are not offered for sale.

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