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Pedestrian Connection System in TOD Areas: User Satisfaction Assessment of Guangzhou Rail Transit Stations

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Abstract: *This study evaluates the pedestrian connection system in Transit-Oriented Development (TOD) areas surrounding rail transit stations in Guangzhou, China. Using a mixed-methods approach combining structured questionnaire surveys (n=546) and preliminary observational fieldwork across nine representative TOD stations, a four-dimensional satisfaction assessment framework — encompassing accessibility, safety, comfort, and pleasure — was developed and applied. Results indicate that overall pedestrian satisfaction remains at a moderate-to-high level, with safety scoring highest (3.825/5) and comfort scoring lowest (3.800/5). Barrier-free facilities recorded the lowest individual score (3.77/5) among all eighteen indicators. A statistically strong negative correlation (r=−0.705 to −0.780, p<0.01) was identified between perceived walking distance and satisfaction across all dimensions, indicating that environmental quality substantially mediates pedestrians' psychological perception of distance. Elderly residents, migrant workers, and low-income groups systematically reported lower satisfaction levels, highlighting spatial equity concerns. The research contributes an empirically grounded evaluation framework applicable to high-density Chinese cities and provides practical implications for sustainable TOD planning and pedestrian environment improvement.*

Keywords: *TOD; Pedestrian connection; User satisfaction; Rail transit; Guangzhou; Built environment*

1. Introduction

China's rapid urbanisation has generated enormous pressure on urban transportation infrastructure. In Guangzhou — one of China's largest metropolitan cities — the metro network spans over 500 kilometres across 13 lines, carrying approximately 6.46 million daily passenger trips. To address chronic challenges of traffic congestion, environmental degradation, and inefficient landuse, Transit-Oriented Development (TOD) has become a central urban planning strategy in Guangzhou, with over 20 TOD projects completed or under active development as of 2024.

TOD promotes high-density, mixed-use urban environments within walkable distances of transit nodes, reducing automobile dependency and encouraging sustainable mobility [1]. Within this framework, the pedestrian connection system serves as the operational backbone linking rail transit infrastructure to surrounding urban functions. Its quality directly determines whether the theoretical benefits of TOD — higher public transit ridership, reduced car use, vibrant urban districts — can be translated into lived experience [2]. The Institute for Transportation and Development Policy (ITDP) explicitly identifies walkability and connectivity as core performance dimensions in its TOD Standard, reinforcing the centrality of pedestrian environments in TOD evaluation [3].

Despite the scale of Guangzhou's TOD programme, systematic user-centred assessment of pedestrian connection system quality remains absent from the research literature. Existing studies have focused predominantly on land use optimisation, property value uplift, and ridership patterns [4][5], while the pedestrian experience within TOD station areas has received limited scholarly attention. This study addresses this gap by: (i) developing a four-dimensional pedestrian satisfaction assessment framework calibrated for Guangzhou's high-density context; (ii) documenting satisfaction profiles across nine representative TOD stations; and (iii) identifying key demographic and distance-related factors mediating pedestrian satisfaction. The findings offer evidence-based guidance for urban planners and policymakers engaged in TOD pedestrian environment improvement.

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2. Literature Review

2.1 TOD Theory and Pedestrian Connectivity

Since Calthorpe's (1993) foundational conceptualisation, TOD theory has consistently positioned pedestrian connectivity as a non-negotiable prerequisite for development success [1]. Cervero (2001) demonstrated that walk-and-ride behaviour is significantly shaped by the quality of pedestrian environments in station vicinities [6]. Schlossberg and Brown (2004) established that walkability constitutes the most important dimension for evaluating TOD performance [7]. Jeffrey et al. (2019) confirmed through evidence from Greater London that the degree of pedestrianisation in TOD areas is a decisive determinant of whether such developments successfully reduce automobile dependency [8]. These findings collectively establish that no excellence in transit infrastructure can compensate for deficiencies in the pedestrian connection system.

2.2 Walking Needs Theory and Evaluation Dimensions

Alfonzo's (2005) hierarchy of walking needs, adapted from Maslow's (1943) motivational framework, identifies five progressive levels of pedestrian need: feasibility, accessibility, safety, comfort, and pleasure [9]. This hierarchy implies that pedestrian satisfaction requires multi-dimensional assessment sensitive to differences between baseline functionality and higher-order experiential richness. Wu and Yu (2020) adapted this framework to the Chinese urban context, demonstrating that direct transplantation of Western walkability models produces systematic measurement distortions, validating the need for context-specific instruments [10].

Walk Score has been widely applied as a quantitative walkability measure but has been criticised for its exclusive focus on objective built environment attributes while neglecting users' subjective evaluations [11]. Mehta (2014) and Ewing and Cervero (2010) both argued that a complete assessment of walking quality must integrate objective physical environment data with subjective user satisfaction measures, as these dimensions capture complementary aspects of pedestrian experience [12][13].

2.3 Built Environment Influences on Walking

Cervero and Kockelman's (1997) 5D framework — Density, Diversity, Design, Destination accessibility, and Distance to transit — remains the canonical analytical tool for understanding built environment influences on walking behaviour [14]. Their meta-analysis confirmed that street-level design variables, land use diversity, and pedestrian network connectivity are among the strongest predictors of walking activity. In the Guangzhou context, Li et al. (2020) demonstrated spatially differentiated impacts of fine-grained built environment characteristics on metro ridership across 220 stations, confirming that TOD performance varies substantially across different urban contexts. However, none of these studies systematically addressed pedestrian satisfaction as an independent outcome variable, confirming the research gap motivating the present inquiry.

3. Research Design

3.1 Study Site Selection

Nine representative TOD rail transit stations in Guangzhou were selected as study sites based on three criteria: typological diversity, variation in TOD implementation maturity, and geographical distribution across central and suburban urban zones. The nine stations are: Taihe Station (S1), Jiahewanggang Station (S2), Science City Station (S3), Guangzhou Railway Station (S4), Guangzhou South Station (S5), Tiyu Xilu Station (S6), Huacheng Avenue Station (S7), Canton Tower Station (S8), and Xintang Station (S9). Walk Score assessments ranged from 52 (S2, S3) to 88 (S7), confirming substantial walkability variation across study sites, as summarised in Table 1.

ISSN 2522-3488 Vol. 10, Issue 1: 64-73, DOI: 10.25236/IJNDES.2026.100109

Table 1: Overview of Nine Study Stations

Station Code	Station Name	Type	Walk Score	Key Features
S1	Taihe	Residential-community	68	Residential-dominant, moderate commercial mix
S2	Jiahewanggang	New town comprehensive	52	Multi-line interchange, mixed new development
S3	Science City	Technology-industrial	51	Industry-dominant, lower pedestrian diversity
S4	Guangzhou Railway	Old-city transport hub	85	High commercial density, historical constraints
S5	Guangzhou South	Regional transport hub	72	High-speed rail interchange, large-scale development
S6	Tiyu Xilu	Urban commercial core	87	High commercial activity, underground connection
S7	Huacheng Avenue	CBD commercial	88	Highest Walk Score, premium pedestrian infrastructure
S8	Canton Tower	Tourism-cultural	80	Tourism-driven activity, landmark orientation
S9	Xintang	Outer-suburban	52	Lower connectivity, emerging development

3.2 Questionnaire Design and Data Collection

A structured questionnaire was developed comprising four modules: (i) respondent sociodemographic profile; (ii) rail transit usage behaviour; (iii) walking connection preferences and distance tolerance; and (iv) pedestrian connection satisfaction measured via an 18-item five-point Likert scale across four dimensions — accessibility (6 items), safety (2 items), comfort (4 items), and pleasure (6 items). The questionnaire was administered online. Of 627 questionnaires distributed, 546 valid responses were collected (response rate: 87%). Internal consistency was confirmed (Cronbach's α=0.963), and construct validity was verified through factor analysis (KMO=0.986; Bartlett's χ^2=7063.574, df=153, p=0.000; variance explained=61.372%). All factor loadings exceeded 0.40 and communalities exceeded 0.40, confirming psychometric adequacy.

3.3 Observational Fieldwork and Data Analysis

Systematic field observations were conducted at all nine stations during three time periods: morning peak (07:00–08:00), mid-morning off-peak (09:00–10:00), and evening peak (19:00–20:00). Observational data encompassed land use mapping within 800-metre catchment areas, Walk Score calculation, pedestrian crossing facility enumeration, and barrier-free infrastructure assessment.

Quantitative data analysis employed three statistical methods: descriptive statistics for respondent profiles and satisfaction score distributions; Pearson correlation analysis examining relationships between sociodemographic variables, distance tolerance, and satisfaction dimensions; and word

ISSN 2522-3488 Vol. 10, Issue 1: 64-73, DOI: 10.25236/IJNDES.2026.100109

frequency analysis of open-ended responses to identify key improvement priorities.

4. Results and Analysis

4.1 Respondent Profile

The 546 valid respondents were predominantly aged 18–35 years (37.00%, n=202), with near-equal gender distribution (female: 51.28%). Residential status showed 64.29% permanent local residents and 26.74% non-resident visitors. Over 68% of respondents fell into the lower-to-middle income bracket (annual household income below RMB 200,000). Family sizes were concentrated at three and four persons per household (65.57% combined). These characteristics broadly reflect the typical Guangzhou metro user profile.

Regarding travel behaviour, entertainment and shopping constituted the most frequent trip purpose (30.59%), substantially exceeding commuting (14.10%), confirming that Guangzhou metro serves highly diverse mobility needs. Weekly travel frequency was concentrated in the moderate-to-high range, with 37.00% of respondents travelling 6–10 times per week. Walking was selected as the preferred connection mode primarily for time efficiency (41.21%) and cost saving (26.19%), indicating that pedestrian access is both functionally and economically significant for users (Table 2).

Table 2: Key Travel Behaviour Statistics (n=546)

Variable	Category	Frequency	Percentage (%)
Trip Purpose	Entertainment/Shopping	167	30.59
	Visiting family/friends	130	23.81
	Tourism	110	20.15
	Commuting	77	14.10
	Business	44	8.06
	Study	18	3.30
Weekly Frequency	6–10 times	202	37.00
	3–5 times	180	32.97
	1–2 times	117	21.43
	10+ times	47	8.61
Walking Mode Reason	Nearest/time saving	225	41.21
	Cost saving	143	26.19
	Avoid transfers	116	21.25
	Health/exercise	50	9.16

4.2 Acceptable Walking Distance

Findings revealed that 39.56% of respondents accepted walking distances up to 400 metres, and 32.60% accepted 400–800 metres, with over 72% of respondents concentrating acceptable walking distances within 800 metres. An additional 16.67% accepted distances of 801–1,000 metres, supporting the designation of 800–1,000 metres as the primary walking service radius for TOD planning in Guangzhou (Table 3).

ISSN 2522-3488 Vol. 10, Issue 1: 64-73, DOI: 10.25236/IJNDES.2026.100109

Table 3: Acceptable Walking Distance Distribution (n=546)

Distance Range	Frequency	Percentage (%)	Cumulative (%)
≤400 metres	216	39.56	39.56
401–800 metres	178	32.60	72.16
801–1,000 metres	91	16.67	88.83
1,001–1,500 metres	46	8.42	97.25
>1,500 metres	15	2.75	100.00

4.3 Multi-Dimensional Satisfaction Assessment

Overall satisfaction scores across the four dimensions ranged from 3.800 to 3.825 on a five-point scale, indicating moderate-to-high satisfaction that nonetheless falls meaningfully short of the "high satisfaction" threshold (≥4.0). Safety recorded the highest dimensional score (3.825), followed by pleasure (3.822), accessibility (3.818), and comfort (3.800). Among individual indicators, barrier-free facility adequacy (3.77) and rest facility quantity (3.76) recorded the two lowest scores across the entire 18-item instrument, identifying these as the most urgent improvement priorities (Table 4).

Table 4: Pedestrian Connection System Satisfaction Scores (n=546)

Dimension	Indicator	Score	Dimension Mean
Accessibility	Pedestrian accessibility	3.88	3.818
	Path boundary clarity	3.81	
	Pedestrian network development	3.82	
	Multimodal connection quality	3.79	
	Barrier-free facilities	3.77 (lowest)	
	Directional signage	3.84	
Safety	Traffic calming and crossing aids	3.82	**3.825** (highest)
	Night-time lighting	3.83	
Comfort	Walking space width	3.84	**3.800** (lowest)
	Pavement surface condition	3.82	
	Sun/rain shelter provision	3.80	
	Rest facility quantity	3.76 (2ndlowest)	
Pleasure	Green/tree canopy coverage	3.85	**3.822**
	Building colour and aesthetics	3.82	
	Cultural landscape features	3.79	
	Street enclosure quality	3.80	
	Commercial environment vitality	3.85	

ISSN 2522-3488 Vol. 10, Issue 1: 64-73, DOI: 10.25236/IJNDES.2026.100109

4.4 Demographic Variables and Satisfaction

Correlation analysis between sociodemographic variables and satisfaction dimensions revealed consistent and statistically significant patterns (Table 5). Age showed a weak-to-moderate negative correlation with satisfaction across most indicators ($r=-0.089$ to -0.177, $p<0.05$), indicating that older respondents systematically reported lower satisfaction — a finding attributable to the pronounced deficiencies in barrier-free facilities, rest provisions, and signage legibility that disproportionately affect elderly users. Residential status (local versus non-local) exhibited the strongest negative correlations of all demographic variables ($r=-0.119$ to -0.224, $p<0.01$), with migrant and transient populations reporting systematically inferior satisfaction levels, suggesting persistent spatial equity concerns in the distribution of pedestrian environment quality. Household income showed moderate negative correlations ($r=-0.064$ to -0.185, $p<0.05$), while gender and family size demonstrated no statistically significant associations with satisfaction outcomes.

Table 5: Selected Correlation Coefficients between Demographic Variables and Satisfaction (n=546)

Demographic Variable	Accessibility	Safety	Comfort	Vibrancy	Overall Satisfaction
Gender	0.041	0.038	0.052	0.047	0.045
Age	−0.138*	−0.112*	−0.165**	−0.143*	−0.152*
Education Level	0.093	0.076	0.088	0.102	0.091
Occupation Type	−0.107*	−0.089	−0.118*	−0.098	−0.103*
Monthly Income	0.176**	0.154**	0.189**	0.168**	0.181**
Residential Status	−0.198**	−0.176**	−0.214**	−0.191**	−0.224**
Trip Frequency	0.083	0.071	0.079	0.064	0.075
Primary Trip Purpose	−0.062	−0.058	−0.071	−0.066	−0.064
Perceived Walking Distance	−0.721**	−0.705**	−0.763**	−0.748**	−0.780**

Note: **p<0.01, *p<0.05. Correlation coefficients below 0.2 indicate weak association; 0.2–0.4 moderate; above 0.4 strong.

4.5 Walking Distance Tolerance and Satisfaction

The correlation analysis between walking distance tolerance and satisfaction indicators yielded the most striking finding of this study. Acceptable walking distance (Q13) demonstrated strong negative correlations with all 18 satisfaction indicators ($r=-0.705$ to -0.780, $p<0.01$), while additional walking distance pressure tolerance (Q14) showed moderate-to-strong negative correlations ($r=-0.551$ to -0.633, $p<0.01$), as presented in Table 6.

ISSN 2522-3488 Vol. 10, Issue 1: 64-73, DOI: 10.25236/IJNDES.2026.100109

Table 6: Correlation between Walking Distance Tolerance and Satisfaction Indicators (n=546)

Satisfaction Indicator	Acceptable Walking Distance (Q13)	Additional Distance Pressure (Q14)
Pedestrian accessibility (Q15)	−0.748**	−0.626**
Pedestrian network development (Q17)	−0.774**	−0.612**
Barrier-free facilities (Q18)	−0.745**	−0.603**
Traffic calming facilities (Q21)	−0.775**	−0.604**
Night-time lighting (Q22)	−0.756**	−0.633**
Walking space width (Q23)	−0.731**	−0.612**
Sun/rain shelter (Q25)	−0.739**	−0.613**
Rest facility quantity (Q26)	−0.713**	−0.609**
Cultural landscape features (Q29)	−0.780**	−0.598**
Commercial environment (Q31)	−0.746**	−0.575**
Correlation range	−0.705 to −0.780	−0.551 to −0.633

Note: **p<0.01. All coefficients are statistically significant.

The uniformly strong negative correlations across all satisfaction dimensions confirm a critical mechanism: perceived walking distance is not a fixed objective quantity but a subjectively mediated experience substantially shaped by environmental quality. When pedestrian environments are well-equipped with shade, seating, legible signage, and attractive landscapes, the same physical distance is psychologically compressed; conversely, deficient environments amplify perceptions of distance and discourage walking behaviour. This finding carries direct planning implications: improvements to pedestrian environment quality function not merely as ends in themselves, but as indirect instruments for extending the effective walking service radius of TOD stations and increasing transit ridership.

4.6 Inter-Dimensional Correlation

Cross-dimensional correlation analysis confirmed that the four satisfaction dimensions are mutually reinforcing. All cross-dimensional indicator pairs showed moderate-to-strong positive correlations ($r=0.525$ to 0.635, $p<0.01$), indicating robust “spillover effects” — improvements in one environmental dimension tend to generate corresponding uplifts in users' evaluations of other dimensions. This systemic interdependence implies that piecemeal, single-dimension interventions are unlikely to produce substantial overall satisfaction gains; comprehensive, multi-dimensional improvements are required to generate meaningful and durable enhancements to the pedestrian experience.

4.7 Key Improvement Priorities from Open-Ended Responses

Word frequency analysis of open-ended improvement suggestions identified five highest-priority themes, presented in descending order of mention frequency: (1) installation of sun/rain shelters and shading structures (approximately 45% of respondents); (2) provision of adequate public seating (approximately 43%); (3) availability of public restrooms (approximately 40%); (4) enhanced greenery and tree planting (approximately 35%); and (5) improvement of barrier-free facilities (approximately 34%). These qualitatively identified priorities align closely with the quantitatively identified lowest-scoring indicators — rest facility quantity (3.76) and barrier-free facilities (3.77) — providing robust cross-method validation of the core findings.

ISSN 2522-3488 Vol. 10, Issue 1: 64-73, DOI: 10.25236/IJNDES.2026.100109

5. Discussion

5.1 Safety and Comfort as Co-Primary Drivers of Satisfaction

Prevailing pedestrian behaviour research has generally positioned safety as the primary determinant of walking satisfaction, with comfort occupying a secondary role (Loukaitou-Sideris & Eckelman, 2013; Alfonzo, 2005). The findings of this study partially support this position but introduce an important qualification specific to the Guangzhou high-density context: safety and comfort emerge as co-primary drivers of satisfaction rather than strictly hierarchical factors. Safety scored highest among the four dimensions (3.825), consistent with its theoretically established primacy. However, the gap between safety and comfort scores (0.025 points) is negligibly small, and comfort deficiencies — particularly sun/rain shelter provision, rest facilities, and walking space width — generated the most concentrated user dissatisfaction, as confirmed by both quantitative scoring and open-ended responses.

A plausible explanation for this pattern is that Guangzhou's safety infrastructure has reached a sufficient baseline level to reduce safety concerns below the threshold that dominates satisfaction formation. Under these conditions, comfort deficiencies become relatively more salient as satisfaction determinants. This finding echoes Mehta's (2014) proposition that as urban pedestrian infrastructure matures, comfort factors progressively displace safety as the primary bottleneck constraining walking activity. The subtropical climate of Guangzhou amplifies this dynamic: high temperatures and heavy rainfall during the summer months render sun/rain shelter inadequacy acutely consequential for walking behaviour in ways that would be far less significant in temperate urban contexts.

5.2 Systemic Disadvantage of Vulnerable User Groups

The consistent negative correlations between elderly status, non-local residential status, lower income levels, and satisfaction across multiple dimensions constitute arguably the most policy-significant finding of this study. These correlations document a systematic pattern of spatial disadvantage among the groups most dependent on public transit and walking as their primary mobility resources.

For elderly residents, the combination of declining physical capacity, increased susceptibility to fall risk on uneven surfaces, and heightened cognitive demand of navigating poorly designed environments interacts with Guangzhou's documented deficiencies in barrier-free facilities to produce disproportionate experiential penalties. The negative correlation between age and barrier-free satisfaction ($r=-0.177$) was among the strongest age-related associations across the entire instrument, underscoring the severity of this mismatch.

For non-local residents and migrants, the strongest negative correlations (peaking at $r=-0.224$ for commercial environment satisfaction) likely reflect a compound disadvantage: unfamiliarity with station area layouts combined with inadequate multilingual signage, reduced financial flexibility for alternative transport options, and residential concentration in areas with lower-quality pedestrian infrastructure. TOD's theoretical commitment to equitable and inclusive urban mobility stands in considerable tension with the documented reality that the groups most dependent on pedestrian access to transit systematically experience inferior conditions.

These findings extend the spatial equity discourse in TOD research beyond its conventional focus on property value displacement and gentrification effects, documenting instead the distributional inequity embedded in the quality of the physical pedestrian environment itself.

5.3 Environmental Quality as a Mediator of Perceived Distance

The strong negative correlations between perceived walking distance and all satisfaction dimensions ($r=-0.705$ to -0.780) constitute the most theoretically novel contribution of this study. This finding provides robust empirical support for what has previously been largely a theoretical proposition — that perceived distance is not isomorphic with physical distance but is substantially mediated by environmental quality (Lam & Morrall, 1982). In the Guangzhou context, the magnitude of this mediation effect (correlation coefficients consistently exceeding -0.70) is substantially higher than comparable effects reported in temperate Western urban contexts, suggesting that climate-specific environmental interventions — shade provision, weather protection, cooling landscaping — may yield disproportionately large distance-perception benefits in subtropical cities.

The practical implications of this finding are substantial. TOD station catchment area planning has

ISSN 2522-3488 Vol. 10, Issue 1: 64-73, DOI: 10.25236/IJNDES.2026.100109

conventionally relied on fixed physical distance thresholds (typically 400–800 metres) as the primary determinant of service radius. The present findings suggest that this approach systematically underestimates the potential walking service radius in high-quality environments and overestimates it in deficient ones. A quality-weighted walking service radius model — incorporating environmental quality scores as modifiers of the base distance threshold — would more accurately capture the effective pedestrian catchment of TOD stations and provide a more reliable basis for transit-supportive land use planning decisions.

6. Conclusions

This study developed and applied a four-dimensional user satisfaction assessment framework for pedestrian connection systems in Guangzhou's TOD rail transit station areas, generating the following principal conclusions.

First, overall pedestrian satisfaction across Guangzhou's TOD station areas is at a moderate-to-high level but falls short of the high-satisfaction threshold, with comfort (3.800) as the lowest-scoring dimension and barrier-free facilities (3.77) and rest facility provision (3.76) representing the most acute deficiencies. These shortfalls demand prioritised planning and investment attention.

Second, safety and comfort function as co-primary drivers of pedestrian satisfaction in Guangzhou's high-density subtropical context, modifying the strictly hierarchical relationship posited by earlier theoretical frameworks. The particular salience of comfort factors is amplified by the city's demanding climatic conditions, making climate-adaptive pedestrian infrastructure — sun/rain shelters, shade trees, rest nodes — especially critical improvement priorities.

Third, elderly residents, non-local populations, and lower-income groups systematically report inferior satisfaction across multiple dimensions, documenting distributional inequity in the pedestrian environment that contradicts TOD's foundational commitment to inclusive urban mobility. Vulnerable group satisfaction should be adopted as an independent monitoring indicator in TOD evaluation frameworks.

Fourth, environmental quality exerts strong mediating effects on perceived walking distance, with correlations of $r=-0.705$ to -0.780 between acceptable distance tolerance and satisfaction indicators. This finding validates the 800–1,000 metre range as the appropriate walking service radius for Guangzhou TOD planning while demonstrating that high-quality environments can effectively extend pedestrians' psychological distance tolerance, thereby expanding station catchment areas and supporting ridership growth without requiring additional physical infrastructure investment.

Fifth, the systemic interdependence of satisfaction dimensions — evidenced by cross-dimensional correlations of $r=0.525$ to 0.635 — confirms that sustainable improvements to pedestrian satisfaction require comprehensive, multi-dimensional environmental upgrades rather than isolated, single-factor interventions.

These conclusions carry direct implications for Guangzhou's ongoing TOD programme. Planners are urged to: (i) prioritise barrier-free infrastructure as an immediate remediation target across all station areas; (ii) systematically install sun/rain shelters and rest facilities along primary pedestrian routes, with particular attention to subtropical climate adaptability; (iii) adopt quality-weighted walking service radius models that account for environmental mediation effects on perceived distance; (iv) establish dedicated monitoring of vulnerable-group satisfaction as a core equity indicator in TOD performance assessment systems; and (v) pursue comprehensive rather than piecemeal pedestrian environment improvements to leverage inter-dimensional spillover effects. These measures would substantially advance the goal of making Guangzhou's TOD areas genuinely pedestrian-friendly, inclusive, and conducive to the sustainable urban mobility patterns that TOD is designed to promote.

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ISSN 2522-3488 Vol. 10, Issue 1: 64-73, DOI: 10.25236/IJNDES.2026.100109

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