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# Station Geography Precedes Station Ranking: Multiscale Territories and Spatial Policy Diagnosis in Taipei Metro

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**Research Article**

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# Station Geography Precedes Station Ranking: Multiscale Territories and Spatial Policy Diagnosis in Taipei Metro


## Abstract

Metro-station assessments frequently aggregate local conditions and network importance without examining the spatial territories to which indicators refer. This study develops Station Geography as a relational, scalar, and evaluative framework for spatial policy diagnosis in Taipei Metro. A Fuzzy Delphi and Grey Analytic Network Process assessment of 12 focal stations is situated within an analysis of 118 physical station areas, 388 entrances, passenger demand, and network centrality. Entrance-based Euclidean territories at 400, 800, and 1,200 m identify spatial overlap; clustering identifies station types; and 200,000-draw score-interval simulations examine ranking sensitivity. Median territorial overlap increases from 0.046 at 400 m to 0.655 at 800 m and 0.944 at 1,200 m, indicating that larger territories increasingly represent shared corridors rather than exclusive station areas. A core-network/local-peripheral partition provides the strongest tested classification. Within the focal set, composite scores correlate with node function (Spearman's rho = 0.853), annual demand (0.846), and 800 m overlap (0.860), demonstrating that the assessment captures more than pedestrian conditions alone. Taipei Main Station remains a stable upper-tier case, while middle ranks vary across distributional, dependence, interval-width, and comparison-set assumptions. Territorial sensitivity and score sensitivity are complementary analyses, not a joint re-estimation of indicators at each radius. The findings support explicit spatial attribution, context-sensitive benchmarking, and differentiated station-area diagnosis rather than a universal ranking.



Keywords: station geography; spatial scale; overlapping territories; metro station areas; node-place model; spatial policy diagnosis

## 1. Introduction

Spatial evaluation begins by defining what is being compared. Metro stations are network nodes, urban places, and entrance-and-route systems, yet station scores are often interpreted without examining the territories represented by their indicators. Station-area research has moved beyond distance-to-transit measures toward node-place relations, station typologies, pedestrian networks, public-space experience, and multiscale accessibility (Vale, 2015; Lyu et al., 2016; Otsuka et al., 2022; Tuvikene et al., 2023). This study uses Station Geography to connect these dimensions to an applied question: when neighbouring stations share urban space but perform different network roles, what does a comparative score mean?

In Taipei, this problem is consequential because the 2025 network contains 118 physical station areas across six lines and the entrance inventory records 388 entrances. Official flow data show strong spatial concentration of passenger activity, while earlier evidence links neighbourhood density, land use, and network characteristics to station-level transit use (Andersson et al., 2021). An assessment that ignores metropolitan position may therefore reproduce existing demand and centrality hierarchies rather than isolate pedestrian or place quality.

Composite indicators organise heterogeneous evidence from built-environment, accessibility, and transit-oriented-development research (Cervero and Kockelman, 1997; Ewing and Cervero, 2010; Geurs and van Wee, 2004; Singh et al., 2014; Ibraeva et al., 2020). However, positively combining passenger activity, services, population, amenities, connectivity, and pedestrian conditions may conflate metropolitan importance with local quality. A central interchange can score highly despite difficult street-level access, while a peripheral station can score poorly because of structural location rather than pedestrian deficiency.

Spatial boundaries further condition interpretation. Walking distances differ across modes and urban contexts (O'Sullivan and Morrall, 1996; Jiang et al., 2012; El-Geneidy et al., 2014; Tennøy et al., 2022), and buffer size changes estimated built-environment associations with metro use (Liu et al., 2023). Multiple entrances enlarge station footprints, while overlapping territories can assign the same population, facility, or street segment to neighbouring stations. This connects station assessment to the modifiable areal unit and uncertain geographic context problems (Openshaw, 1984; Kwan, 2012). Geometric overlap nevertheless remains distinct from route-sensitive pedestrian access (D'Orso and Migliore, 2020).

Indicators also require behavioural validation. Jeffrey et al. (2019) related station walkability types to access mode and patronage, while He and He (2025) showed that walkability associations vary by time of day. Network position and observed demand provide useful context, but neither is a direct measure of pedestrian experience. Accordingly, the present analysis examines the meaning of a composite assessment rather than treating correlations with demand as validation of walkability.

Evaluation also contains bounded judgement. Fuzzy Delphi screening expresses consensus, while the Grey Analytic Network Process (Grey-ANP) preserves intervals around expert priorities (Chang et al., 2000; Saaty, 1977; Lin and Wei, 2018). Rank-acceptability research shows that an exact ordering can conceal alternative conclusions under different assumptions (Lahdelma and Salminen, 2001; Tervonen and Figueira, 2008). Spatial diagnosis therefore requires both an explicit geographical comparison unit and an account of which comparative conclusions remain stable.

The Taipei application links a 12-station composite assessment with the 118-station network's entrance geography, demand, centrality, typology, and territorial overlap. Four questions guide the analysis: How do entrance-based territories change across 400, 800, and 1,200 m zones? Which station types emerge system-wide? How strongly do focal-station scores align with network role?

Which ranking conclusions remain stable under alternative score-interval assumptions? The territorial and score analyses address complementary uncertainties; they do not recalculate the 18 indicators at every radius.

The contribution is an integrated spatial diagnostic framework, rather than a new clustering or weighting algorithm. It connects territorial non-exclusivity, metropolitan context, and conditional ranking uncertainty to the interpretation of station performance. Its applied value is to distinguish entrance-level concerns, shared corridor conditions, and network integration before translating a score into a planning response.

## 2. Station geography: spatial foundations and analytical framework

### 2.1. From station-area research to station geography

Station-centred research treats stations as redevelopment sites, node-place relations, transit-oriented districts, pedestrian catchments, and public spaces. Station Geography organises these established perspectives around the spatial interpretation of assessment. It is not a replacement for the node-place model or a claim that every dimension is newly measured here; it makes network role, surrounding place, pedestrian interface, territorial boundaries, environmental context, and differentiated users explicit.

The station-redevelopment and node-place tradition provides the relational foundation. Bertolini (1996, 1999) conceptualised stations as nodes in transport networks and places within urban territories, making development potential dependent on the balance and interaction between accessibility and nearby activities. Subsequent applications used this relation for strategic station assessment in the Netherlands, Tokyo, and wider European settings (Peek et al., 2006; Reusser et al., 2008; Chorus and Bertolini, 2011; Papa and Bertolini, 2015). The central implication is that network role and place intensity are mutually conditioning but cannot be inferred from one another.

Station classification and transit-oriented-development research extend this relational view. Context-based classification warns that passenger volume alone blends performance with the conditions under which a station operates (Zemp et al., 2011). Latent-class, cluster, and extended node-place models distinguish heterogeneous station roles and incorporate pedestrian accessibility, design, people, and network criticality (Higgins and Kanaroglou, 2016; Lyu et al., 2016; Vale et al., 2018; Caset et al., 2019; Zhang et al., 2019). Jeffrey et al. (2019) further demonstrated that station walkability typologies can be validated with access-mode behaviour. These studies support a comparative premise: plural station geographies should be identified before one universal benchmark is used to diagnose performance.

Station territory and spatial scale form a third strand. Access distance, street networks, corridor form, and entrances alter the opportunities attributed to stations (Jiang et al., 2012; El-Geneidy et al., 2014; Vale, 2015; Otsuka et al., 2022). Buffer-size sensitivity can change estimated ridership associations (Liu et al., 2023), while connectivity and route quality represent different access dimensions (D'Orso and Migliore, 2020). The modifiable areal unit and uncertain geographic context problems therefore make station territory a substantive analytical choice, not a neutral container (Openshaw, 1984; Kwan, 2012).

A fourth strand links indicators to behaviour, experience, and distribution. Built-environment measures do not always correspond to observed walking, and their effects can vary by time, purpose, and population (He and He, 2024, 2025; Hsu et al., 2024). Mobilities and public-space scholarship also treats stations as spaces of waiting, encounter, affect, regulation, and uneven capability rather than only transfer devices (Bissell, 2009, 2010; Tuvikene et al., 2023; Otsuka and Reeve, 2024; Haynes, 2025). This scholarship establishes a distributional premise: identical physical and network

arrangements can be experienced differently according to disability, age, gender, encumbrance, time, and institutional rules.

These literatures establish three premises: station performance is relational, territory is scale-dependent, and similar physical configurations may be experienced unequally. Their integration explains why comparable scores need not imply comparable deficiencies or interventions.

### 2.2. Defining station geography: relational, scalar, and evaluative commitments

Station Geography denotes the relational and scale-dependent configuration through which a station's node function, surrounding place, pedestrian interface, metropolitan position, territorial definition, environmental context, and exposed users jointly shape measured performance and policy meaning. Its first commitment is relational: each dimension acquires meaning through its connection with the others. A high-capacity node may coexist with a stressful pedestrian interface; a neighbourhood station may combine modest network reach with strong local accessibility.

Its second commitment is scalar. Station geography can be observed at the entrance, route, catchment, corridor, network, and metropolitan levels, and these levels are not interchangeable. The same station may exhibit strong immediate pedestrian conditions, weak district-level integration, and high network centrality. Spatial scale therefore changes the object of evaluation rather than merely changing measurement resolution.

Its third commitment is evaluative. A station score represents selected dimensions under a stated territorial boundary, normalisation rule, comparison set, weighting structure, and uncertainty model. The 18-indicator system supplies a structured composite representation, but it does not exhaust Station Geography. System-wide network, entrance, demand, and territorial measures provide the geographical context needed to interpret the composite and to separate node importance from pedestrian or place deficiency.

### 2.3. Entrance geography, station territories, and spatial scale

The territorial expression of station geography is commonly represented by a single point and a circular buffer. This is convenient but can be misleading when a station has several entrances distributed across large blocks, underground passages, or opposite sides of an arterial road. Entrance-specific geometry changes both the total area associated with a station and its overlap with neighbouring stations. In a compact network, the question is not merely whether 800 m is a plausible walking distance; it is whether an 800 m attribution remains spatially discriminating and policy-relevant.

Entrance-based zones at multiple radii provide a territorial comparison rather than a claim about actual pedestrian route choice. Street-network distance, slope, crossings, private passages, opening hours, and physical barriers remain distinct features of route accessibility. The overlap share identifies the point at which nominal station territories cease to be geographically exclusive and require an explicit allocation rule.

### 2.4. Ranked station geographies and conditional uncertainty

Grey intervals preserve bounded evaluation rather than forcing expert judgements or station scores into a single point. An interval alone, however, does not define a probability distribution. Uniform, triangular, correlated, and width-adjusted scenarios express different assumptions about values within the same bounds. Rank frequencies are therefore interpreted as conditional simulation results, not as population probabilities or confidence levels.

Three forms of conclusion are distinguished. Dominance is present when one station exceeds another across nearly all plausible values. Tier stability is present when a station remains broadly upper, middle, or lower even though its exact rank changes. Rank fragility appears when the ordering shifts materially under alternative distributions, interval widths, dependence structures, or comparison sets. This distinction connects uncertainty directly to station policy.

### 2.5. Analytical expectations for Taipei's station geographies

Four expectations organise the analysis (Fig. 1): territorial overlap increases sharply with radius; system-wide station types reflect network and metropolitan position; composite scores capture both pedestrian and node-place conditions; and broad ranking tiers are more stable than exact positions. The framework links these findings through interpretation, without assuming that geometric overlap itself causes rank changes.

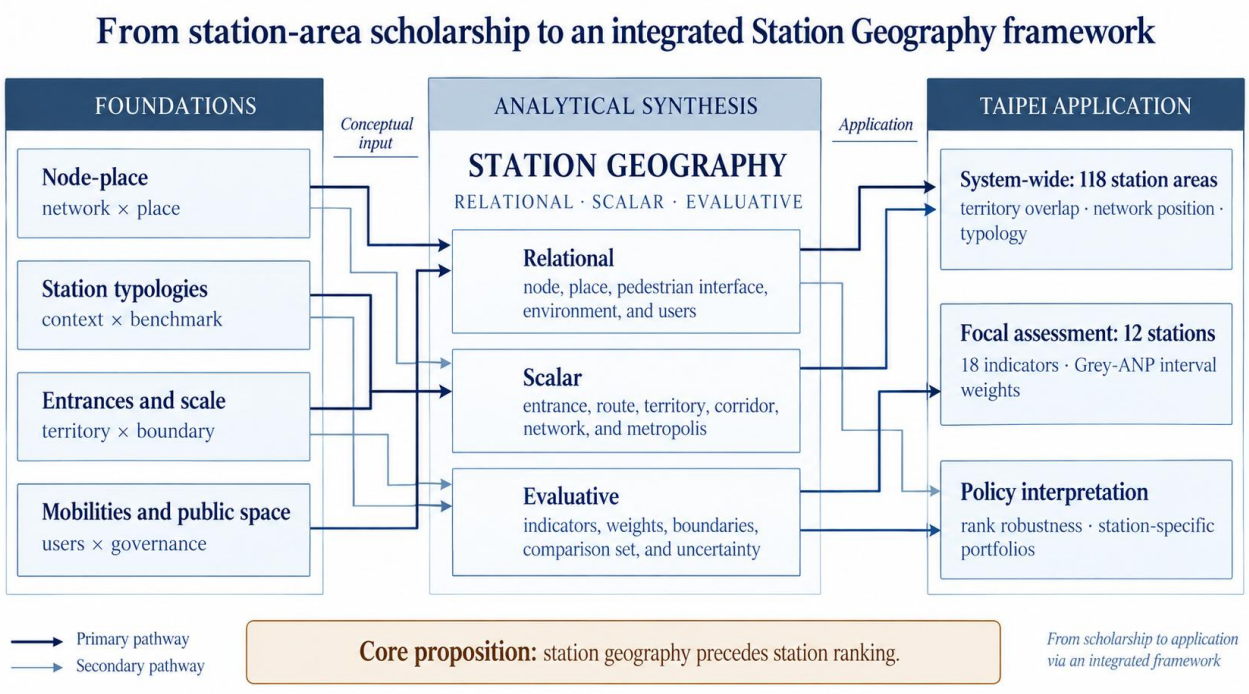



**Fig. 1** Literature foundations and analytical structure of Station Geography. Four research traditions converge on relational, scalar, and evaluative commitments, operationalised through multiscale territories, station types, an 18-indicator assessment, and policy interpretation. Darker and lighter arrows distinguish primary and secondary conceptual pathways, not estimated causal effects

## 3. Data and methods

### 3.1. Study area and integrated research design

The study covers 118 physical station areas across the six-line Taipei Metro operating network in 2025, including the Circular Line (Fig. 2). The system encompasses dense central interchanges, commercial destinations, established neighbourhood stations, peripheral corridors, and branch-line termini. Twelve focal stations represent this diversity: Taipei Main Station, Zhongxiao Fuxing, Taipei 101/World Trade Center (Taipei 101/WTC), Ximen, Taipei City Hall, Daan Park, Gongguan, Beitou, Sanchong, Tamsui, Wanfang Community, and Xiaobitan.

The integrated design connects two analytical scales. The complete network defines metropolitan structure through passenger demand, topology, centrality, entrance geography, accessibility provision, and territorial overlap. The focal set carries the 18-indicator Station Geography assessment and bounded composite scores. Typology and territorial findings therefore describe the

complete network, while score alignment and rank frequencies refer to the focal set. This distinction places each focal station within the metropolitan system without treating 12 purposefully selected cases as a network-wide prevalence sample.

### 3.2. Evaluation dimensions and data

The evaluation comprises five facets and 18 indicators (Table 1). Fuzzy Delphi consensus retained 18 of 25 candidates at a threshold of 7.14, and Grey-ANP represented each indicator with lower, upper, and midpoint weights, consistent with grey-system representation (Deng, 1982). The five facet intervals are land use (14.40-17.97%), public facilities (20.64-23.13%), pedestrian environment (29.97-35.03%), environmental dynamics (5.98-7.84%), and transit environment (17.89-27.14%). Pedestrian friendliness has the largest midpoint weight (12.58%), followed by mass-transit development (10.40%), greening and planting (9.75%), and surrounding population (9.05%).

For descriptive scoring, normalised indicators are aggregated using the central Grey-ANP weights. The equation uses weights expressed as proportions and normalised indicator values for each station. The point scores and lower-upper bounds reported in Table 5 are distinct summaries; a reported point score need not equal the arithmetic midpoint of its score interval.

$$SG_j = 100 \sum_{i=1}^{18} w_i z_{ij}$$

The metropolitan context combines 2025 annual station entries and exits, 2024 totals for year-on-year comparison, the six-line operating topology, and 388 station entrances (Taipei City Government Department of Budget, Accounting and Statistics, 2026; Taipei Rapid Transit Corporation, 2026a, 2026b; New Taipei Metro Corporation, 2026). Network attributes include line count, degree, betweenness, closeness, eigenvector centrality, and topological distance from Taipei Main Station. Entrance attributes include entrance count, accessible-entrance share, mean radius from the entrance centroid, maximum entrance spread, and convex-hull area. Demand and topology refer to calendar year 2025; the entrance inventory carries metadata dated June 2026.

**Table 1. Station Geography evaluation system and Grey-ANP interval weights.**

| Evaluation facet | Indicator | Grey weight interval (%) | Midpoint weight (%) |
|---|---|---|---|
| Land use (14.40-17.97) | Land-use pattern around the station | 5.20-7.52 | 6.36 |
| | Land-use scale | 5.20-6.22 | 5.71 |
| | Building-volume density around the station | 4.01-4.24 | 4.12 |
| Public facilities (20.64-23.13) | Daily-life service facilities | 3.66-4.93 | 4.30 |
| | Open-space service facilities | 7.10-8.00 | 7.55 |
| | Public infrastructure | 2.40-2.49 | 2.45 |
| | Accessibility service facilities | 7.39-7.80 | 7.59 |
| Pedestrian environment (29.97-35.03) | Greening and planting | 8.28-11.22 | 9.75 |
| | Pedestrian friendliness | 10.98-14.18 | 12.58 |
| | Environmental quality improvement | 5.22-5.45 | 5.33 |
| | Evacuation and refuge-space ratio | 4.41-5.26 | 4.84 |
| Environmental dynamics (5.98-7.84) | Local air-quality change | 2.61-3.16 | 2.88 |
| | Local temperature change | 0.37-0.48 | 0.42 |
| | Long-term rainfall change | 0.86-0.91 | 0.89 |
| | Local population composition | 2.15-3.29 | 2.72 |
| Transit environment (17.89-27.14) | Surrounding population | 7.25-10.85 | 9.05 |
| | Road-network connectivity | 2.33-3.78 | 3.06 |
| | Mass-transit development | 8.30-12.51 | 10.40 |

Note: Grey intervals are reported in ascending lower-upper order. Midpoint weights sum to 100%. The five facets form the indicator structure of the Station Geography evaluation.

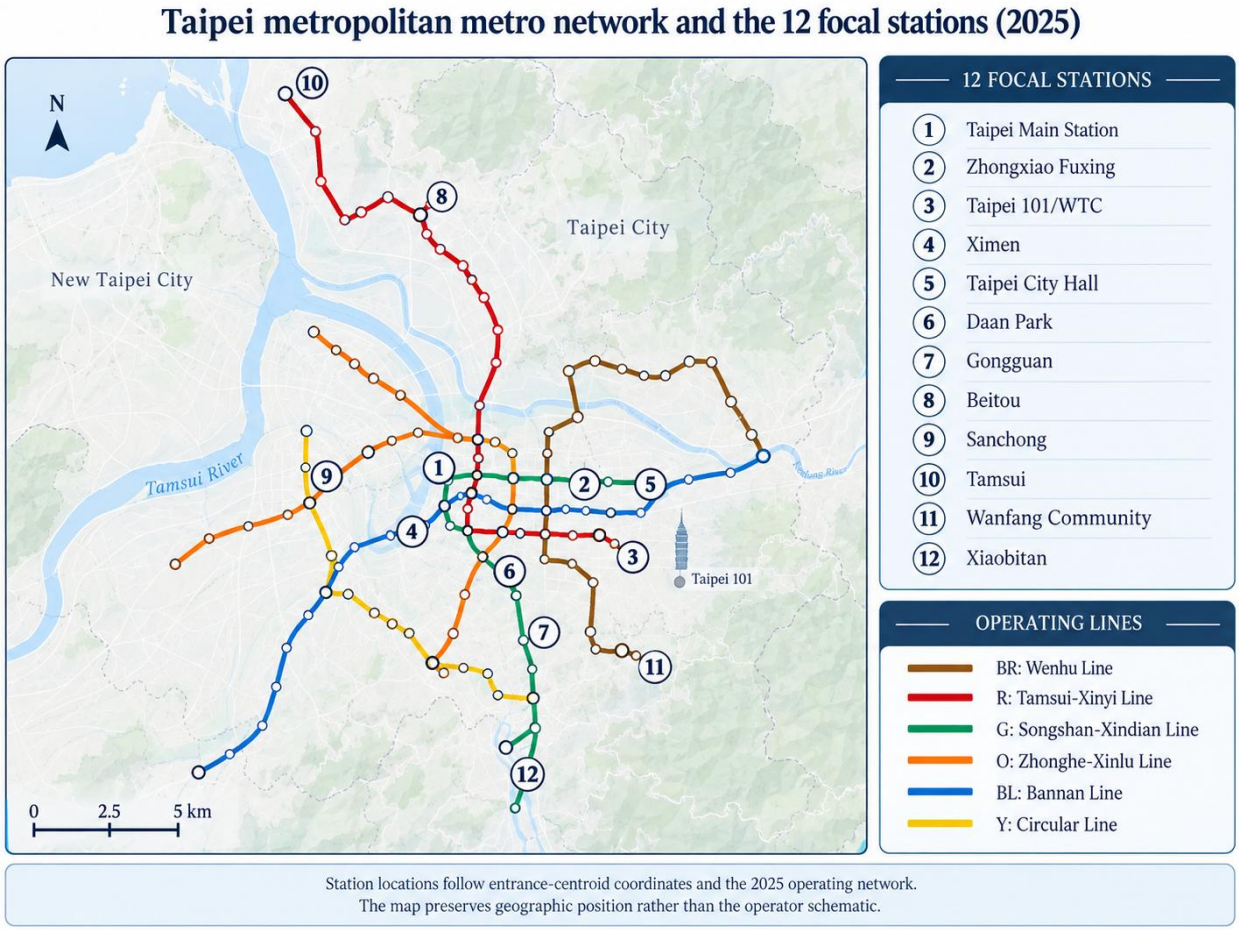



**Fig. 2** Geographic map of the Taipei Metro network and the 12 focal stations. Physical station areas are represented by entrance-centroid points; numbered callouts identify the focal stations. The map preserves geographic position rather than reproducing the operator's schematic passenger map

### 3.3. Multiscale station territories

For any station, the entrance-based territory at a specified radius contains every location whose Euclidean distance to at least one listed entrance does not exceed that radius. The station territory is defined as follows.

$$C_j(r) = \left\{x: \min_{e \in E_j} d(x,e) \le r\right\}$$

The overlap share is the proportion of a station's entrance-based territory also covered by at least one other station. The other-station term in the equation denotes the union of all remaining stations' territories at the same radius, not the geometric complement of the focal territory.

$$O_j(r) = \frac{\text{Area}\left[C_j(r) \cap C_{-j}(r)\right]}{\text{Area}\left[C_j(r)\right]}$$

Territories are compared at 400, 800, and 1,200 m for all 118 station areas and the 12 focal stations. The measure identifies spatial overlap and attribution ambiguity, not street-network travel time, pedestrian barriers, or observed routes. The 18-indicator scores are not re-estimated at these radii; their uncertainty is evaluated separately in Section 3.6.

### 3.4. System-wide station typology

The system-wide typology draws on ten standardised attributes: logarithmic annual entries and exits, entry-exit directional imbalance, line count, betweenness, closeness, entrance count, accessible-

entrance share, maximum entrance spread, 800 m overlap share, and topological distance from Taipei Main Station. Values outside three standard deviations are bounded to reduce the leverage of extreme hubs.

Two- through six-cluster solutions are compared through silhouette width (MacQueen, 1967; Rousseeuw, 1987). The highest silhouette identifies the primary structural partition, while a four-cluster solution provides a higher-resolution policy interpretation. Principal component analysis displays the multivariate geography in two dimensions (Jolliffe and Cadima, 2016); cluster selection remains based on silhouette performance rather than visual separation alone.

### 3.5. Composite-score alignment with network role and metropolitan position

Associations between focal-station composite point scores and metropolitan context are expressed through Spearman correlations with demand, directional imbalance, demand growth, line count, betweenness, closeness, topological distance, accessible-entrance share, 800 m overlap, and a node-function index. The index is the first principal component of log demand, line count, betweenness, closeness, and inverse topological distance; it explains 71.4% of their standardised variance.

Bootstrap intervals use 5,000 resamples, and two-sided permutation tests use 9,999 rearrangements (Efron and Tibshirani, 1993). Partial rank correlation holds line count and topological distance constant. Residual performance is the composite score minus its fitted value on the node-function trend. Residuals describe departures from network-role alignment; they cannot identify the separate contributions of pedestrian quality, place conditions, or omitted influences.

### 3.6. Bounded rank sensitivity

Grey score intervals are examined through 200,000 draws under five assumptions: independent uniform values; independent triangular values with the interval midpoint as the mode; uniform marginals linked by a common-factor Gaussian copula with latent correlation 0.5; intervals narrowed by 25% around their midpoints; and intervals widened by 25%. This score-level sensitivity design addresses distributional, dependence, and interval-width assumptions (Saltelli et al., 2008). Outputs are first-rank frequency, top-three frequency, median rank, and the central 95% rank range.

Comparison-set sensitivity omits each other station in turn and recalculates top-three frequencies among the remaining eleven. These calculations examine rankings within stated score bounds. They do not jointly propagate uncertainty in raw indicator measurement, spatial allocation, expert recruitment, or weight estimation, and do not provide population probabilities.

$$A_j(k) = \frac{1}{B}\sum_{b=1}^{B} \mathbb{I}\left[R_j^{(b)} = k\right]$$

The equation defines the conditional frequency with which a station occupies a specified rank across all simulation draws. It is a simulation-based rank frequency under the stated interval assumptions, not an empirical probability of real-world superiority.

### 3.7. Station-specific policy profiles

The composite score is complemented by four station-specific profiles that retain distinct policy meanings. Access-exposure pressure combines the share of entrances not flagged as accessible with annual passenger demand. Interface complexity combines demand, entrance spread, 800 m overlap, and line count. Peripheral integration combines topological distance, inverse closeness, inverse demand, and inverse line count. The local-activity profile combines the demand residual relative to

node structure, the composite-score residual relative to the node index, and entrance count. Components are standardised and expressed as within-focal-set percentiles.

The profiles retain distinct dimensions rather than form another total score. They support diagnosis within the focal set, not estimates of project benefits, costs, causal effects, or network-wide investment priority. An entrance without an accessibility flag is not necessarily inaccessible, and passenger demand does not reveal how many users encounter an inaccessible route.

OpenAI ChatGPT assisted with manuscript organisation, language editing, and plotting-code preparation; its image-generation function assisted the conceptual layout in Fig. 1. Statistical graphics in Figs. 3 and 5–7 were rendered from the reported numerical results. The author is responsible for the final content.

## 4. Results

### 4.1. Station territories change sharply with spatial scale

Territorial overlap changes sharply with scale (Table 2; Fig. 3). Across 118 station areas, the median share is 0.046 at 400 m, 0.655 at 800 m, and 0.944 at 1,200 m. The proportion of stations with overlap of at least 50% increases from 4.2% to 66.9% and 92.4%, respectively. At 800 m, 25.4% reach at least 90% overlap; at 1,200 m, 61.9% do so.

The central-station-heavy focal set is more overlap-prone: median overlap reaches 0.878 at 800 m and 0.995 at 1,200 m. Half of the focal stations reach at least 90% overlap at 800 m, and three-quarters do so at 1,200 m. Larger zones thus represent shared corridors and districts increasingly strongly. These results identify potential attribution problems; they do not quantify double-counted indicator values or establish that overlap changes the composite ranking.

**Table 2. Scale sensitivity of entrance-based Euclidean station-territory overlap.**

| Scope | Radius (m) | Stations | Median | Interquartile range | Overlap ≥50% | Overlap ≥90% |
|---|---|---|---|---|---|---|
| Full network | 400 | 118 | 0.046 | 0.000-0.177 | 4.2% | 0.0% |
| Full network | 800 | 118 | 0.655 | 0.423-0.896 | 66.9% | 25.4% |
| Full network | 1,200 | 118 | 0.944 | 0.805-0.997 | 92.4% | 61.9% |
| Focal 12 | 400 | 12 | 0.180 | 0.042-0.261 | 8.3% | 0.0% |
| Focal 12 | 800 | 12 | 0.878 | 0.492-0.980 | 75.0% | 50.0% |
| Focal 12 | 1,200 | 12 | 0.995 | 0.911-1.000 | 91.7% | 75.0% |

Note: Overlap is the share of a station's entrance-based territory also covered by at least one other station. The Euclidean zones do not represent street-network walking paths.

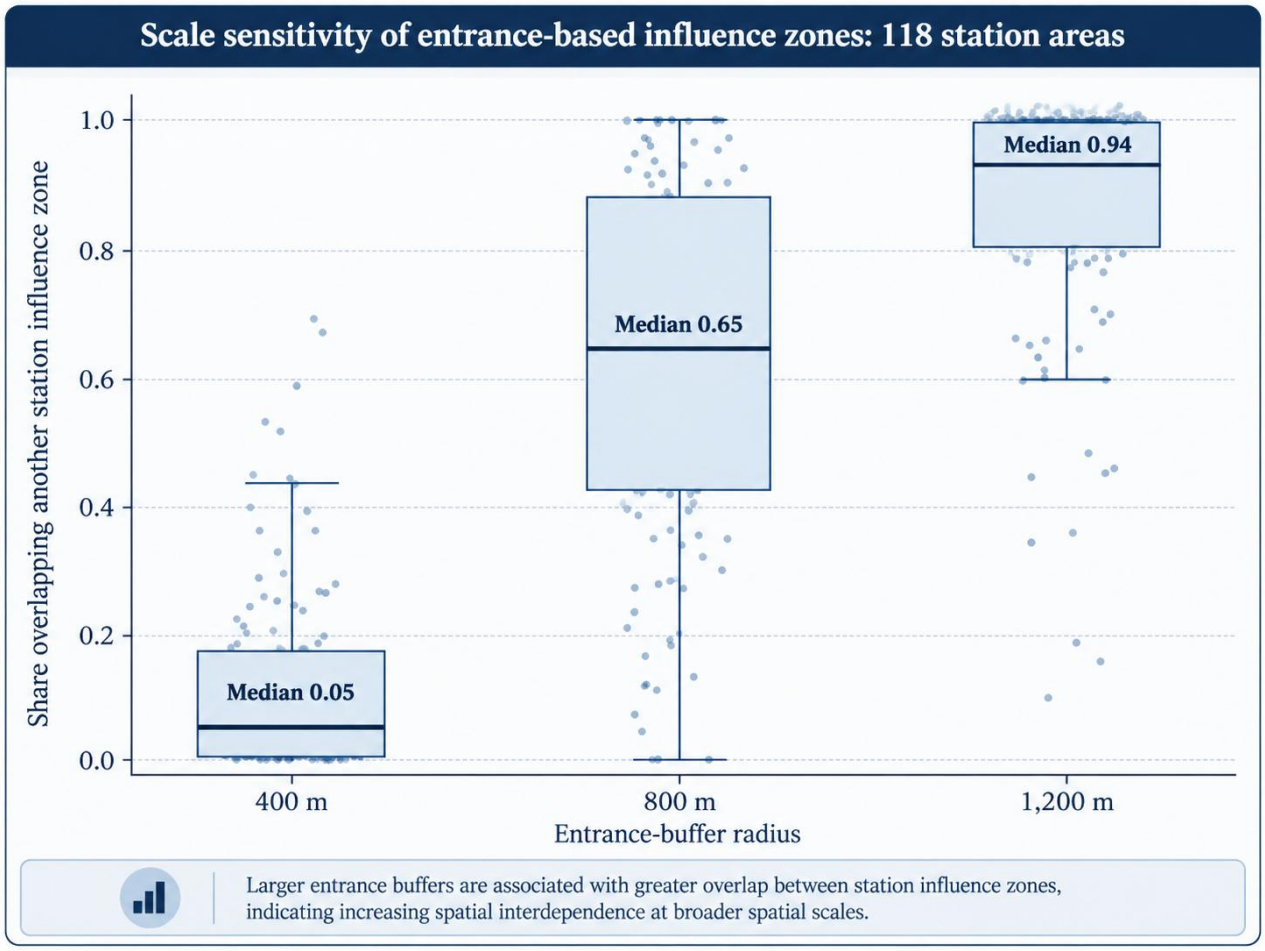



**Fig. 3** Median and interquartile range of territory-overlap shares at 400, 800, and 1,200 m for 118 physical station areas. Boxes span the first to third quartile; internal horizontal rules show the medians reported in Table 2

### 4.2. Taipei's station geographies are organised by a core-periphery structure

The silhouette coefficient is highest for the two-cluster solution (0.314), followed by the three-cluster (0.263) and four-cluster (0.260) solutions. Although the absolute silhouette is modest, the primary solution provides the strongest tested partition and separates 41 core-network stations from 77 local/peripheral stations. Core-network stations have a median of 19.05 million annual entries and exits compared with 7.66 million in the local/peripheral group. They also have more lines, higher betweenness and closeness, more entrances, substantially greater 800 m overlap, and a mean topological distance of 3.31 stops from Taipei Main Station. The local/peripheral group has fewer entrances but a substantially larger mean share designated as accessible (0.788 versus 0.349).

The higher-resolution four-cluster solution provides a more policy-readable interpretation (Table 3 and Fig. 4). Thirteen transfer anchors have a median annual demand of 26.16 million, an average of two lines, 7.15 entrances, 0.970 overlap at 800 m, and the highest centrality. Thirty-nine urban destination/core stations are relatively high-demand and central. Forty-eight neighbourhood-access stations have the highest accessible-entrance share (0.910), fewer entrances, and lower annual demand. Eighteen peripheral/branch stations are farthest from the metropolitan anchor in topological terms, least central, and least overlapped.

Among the 12 focal stations, Taipei Main Station, Zhongxiao Fuxing, and Ximen belong to the transfer-anchor type. Taipei 101/WTC, Taipei City Hall, Daan Park, Gongguan, and Sanchong belong to the urban destination/core type. Beitou, Wanfang Community, and Xiaobitan belong to the neighbourhood-access type, while Tamsui represents the peripheral/branch type. Because the four-

cluster solution does not maximise silhouette and is not nested within the primary partition, its labels provide a higher-resolution interpretation rather than fixed natural classes.

**Table 3. Profiles of the primary and exploratory station typologies.**

| Solution / type | N | Median annual demand | Lines / betweenness | Entrances / accessible share | 800 m overlap / stops |
|---|---|---|---|---|---|
| Two-cluster: core network | 41 | 19,048,594 | 1.39 / 0.131 | 5.46 / 34.9% | 87.5% / 3.31 |
| Two-cluster: local/peripheral | 77 | 7,661,299 | 1.01 / 0.063 | 2.13 / 78.8% | 50.5% / 7.27 |
| Four-cluster: transfer anchors | 13 | 26,156,683 | 2.00 / 0.227 | 7.15 / 30.6% | 97.0% / 2.09 |
| Four-cluster: urban destination/core | 39 | 15,424,967 | 1.05 / 0.098 | 3.97 / 45.3% | 73.6% / 4.05 |
| Four-cluster: neighbourhood access | 48 | 5,689,264 | 1.02 / 0.061 | 1.75 / 91.0% | 60.8% / 6.75 |
| Four-cluster: peripheral/branch | 18 | 9,945,094 | 1.06 / 0.028 | 3.11 / 53.7% | 23.5% / 10.34 |

Note: The two-cluster solution maximises silhouette. The four-cluster solution is exploratory and not nested. Demand is the group median; other profile values are group means. Distance is measured in station-to-station links from Taipei Main Station.

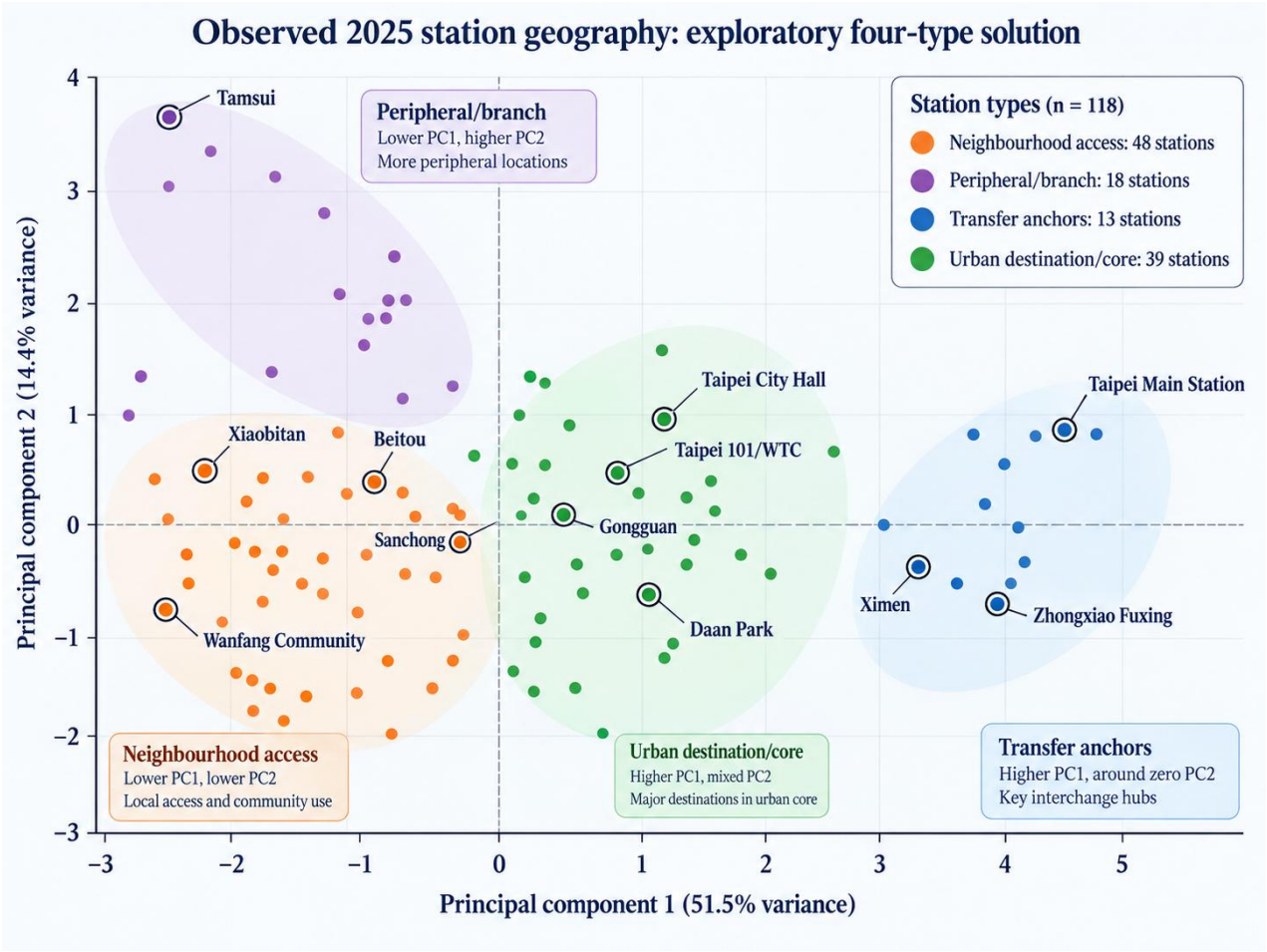



**Fig. 4** Principal-component representation of the exploratory four-type solution for the 2025 Taipei Metro network. The 12 focal stations are outlined and labelled

### 4.3. Composite scores reflect node-place structure

Within the 12 focal stations, composite scores align strongly with node-related attributes (Table 4; Fig. 5). Spearman coefficients are 0.853 for the node-function index, 0.860 for 800 m overlap, 0.846 for annual demand, 0.825 for closeness, 0.697 for line count, and 0.687 for betweenness, compared with -0.720 for topological distance. The node-function index accounts for 68.9% of linear variation in focal-station scores.

The association between score and demand remains positive after line count and topological distance are held constant, with a partial Spearman coefficient of 0.784 and permutation significance of 0.008. Directional imbalance has a coefficient of -0.657, while 2024-2025 demand growth has a weaker coefficient of 0.203. The composite therefore reflects stable metropolitan structure and activity scale more strongly than short-term passenger growth.

The coefficient of -0.765 for accessible-entrance share should not be interpreted as a negative effect of accessibility. It is consistent with the contrast between central stations with numerous entrances but lower designated shares and several lower-demand stations with fewer entrances and higher shares. This descriptive tension warrants route-level investigation, not a conclusion about the accessibility experienced by individual passengers.

Residuals from the node-function trend are positive for Taipei 101/WTC (+8.0 points), Tamsui (+3.8), Taipei City Hall (+3.4), Daan Park (+3.0), Beitou (+2.7), and Taipei Main Station (+2.5). They are negative for Xiaobitan (-9.2), Wanfang Community (-4.7), Ximen (-4.6), Zhongxiao Fuxing

(-2.7), and Sanchong (-2.2); Gongguan is close to the fitted value. These departures are descriptive and do not isolate particular indicator effects.

**Table 4. Associations between composite station scores and 2025 attributes within the 12-station focal set.**

| Station attribute | Spearman coefficient | 95% bootstrap interval | Permutation p-value |
|---|---|---|---|
| Log 2025 annual entries + exits | 0.846 | 0.509 to 0.971 | <0.001 |
| 2025 entry-exit directional imbalance | -0.657 | -0.925 to -0.164 | 0.026 |
| 2024-2025 station demand growth | 0.203 | -0.412 to 0.792 | 0.509 |
| Metro line count | 0.697 | 0.394 to 0.878 | 0.020 |
| Network betweenness | 0.687 | 0.102 to 0.949 | 0.017 |
| Network closeness | 0.825 | 0.464 to 0.972 | 0.001 |
| Topological distance from Taipei Main (stops) | -0.720 | -0.928 to -0.276 | 0.010 |
| Accessible entrance share | -0.765 | -0.950 to -0.293 | 0.003 |
| 800 m influence-zone overlap share | 0.860 | 0.517 to 0.978 | <0.001 |
| Composite node-function index | 0.853 | 0.496 to 1.000 | <0.001 |

Note: Intervals use 5,000 bootstrap resamples, and permutation significance uses 9,999 rearrangements. Results are exploratory because the 12 focal stations were purposefully selected and the node-function index is estimated within this set.

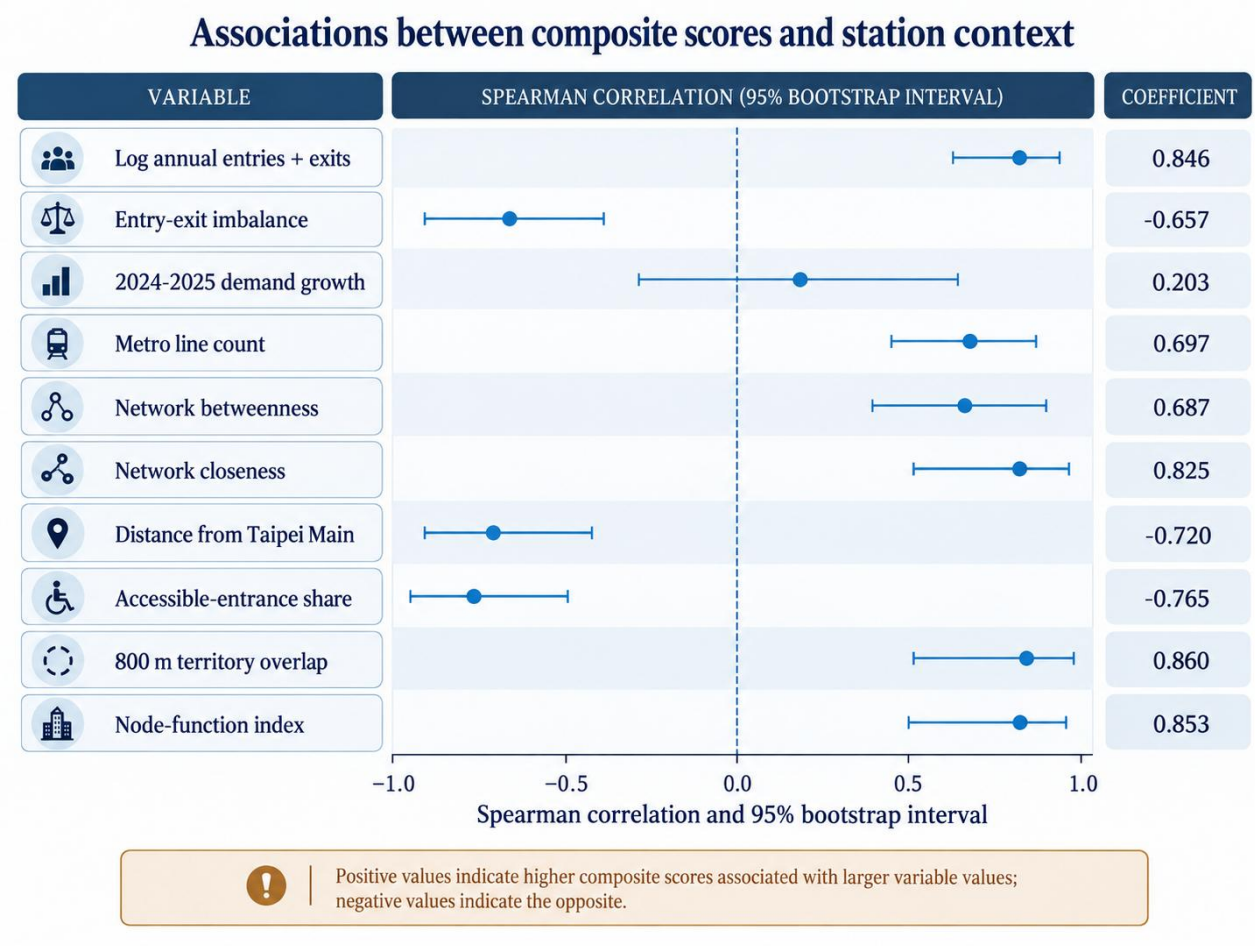



**Fig. 5** Associations between composite scores and station context. Points and horizontal intervals show the Spearman coefficients and 95% bootstrap intervals in Table 4. The vertical reference line marks zero correlation

### 4.4. The upper anchor is stable, but exact middle ranks are assumption-sensitive

All percentages in this section are conditional frequencies within the focal comparison set (Table 5; Fig. 6). Taipei Main Station remains a stable upper-tier case: its first-rank frequency ranges from 68.3% to 94.3%, while its top-three frequency is at least 96.2% under every scenario. Stability of the upper tier does not imply certainty about first place.

The middle of the ordering is considerably less distinct. Zhongxiao Fuxing has a top-three frequency ranging from 65.3% to 84.4%; Taipei 101/WTC ranges from 46.3% to 53.0%; Ximen from 36.1% to 40.2%; and Taipei City Hall from 19.5% to 30.2%. Median ranks are more stable than exact frequencies, but rank intervals overlap widely. Under the uniform baseline, Taipei 101/WTC occupies ranks 1-7 across the central 95% of draws, Ximen ranks 1-8, and Taipei City Hall ranks 2-8.

Omitting another station changes top-three frequencies even though no station score changes. Taipei Main Station retains median rank 1 and a top-three frequency of 99.1%-99.9%; several other central stations show wider comparison-set sensitivity (Table 5). The result supports reporting a stable upper-tier case and overlapping comparative groups rather than treating a precise ordering as an investment decision.

**Table 5. Conditional rank-frequency sensitivity across five interval scenarios and leave-one-out comparison sets.**

| Station | Point score [bounds] | First-rank frequency range | Top-three frequency range | Median-rank range | Leave-one-out top-three range |
|---|---|---|---|---|---|
| Taipei Main Station | 85 [80-90] | 68.3-94.3% | 96.2-100.0% | 1-1 | 99.1-99.9% |
| Zhongxiao Fuxing | 80 [75-85] | 4.0-13.7% | 65.3-84.4% | 2-3 | 71.8-89.0% |
| Taipei 101/WTC | 78 [72-84] | 0.9-7.7% | 46.3-53.0% | 3-4 | 47.7-67.8% |
| Ximen | 77 [70-84] | 0.5-7.5% | 36.1-40.2% | 4-4 | 39.4-56.4% |
| Taipei City Hall | 76 [70-82] | 0.0-2.4% | 19.5-30.2% | 5-5 | 27.3-47.1% |
| Daan Park | 75 [68-80] | 0.0-0.3% | 5.6-14.8% | 6-6 | 11.6-27.5% |
| Gongguan | 72 [65-78] | 0.0-0.0% | 0.6-6.1% | 7-7 | 3.0-10.9% |
| Beitou | 70 [60-75] | 0.0-0.0% | 0.0-0.5% | 8-9 | 0.1-0.9% |
| Sanchong | 68 [60-74] | 0.0-0.0% | 0.0-0.3% | 9-9 | 0.0-0.4% |
| Tamsui | 66 [55-72] | 0.0-0.0% | 0.0-0.0% | 10-10 | 0.0-0.0% |
| Wanfang Community | 60 [50-68] | 0.0-0.0% | 0.0-0.0% | 11-11 | 0.0-0.0% |
| Xiaobitan | 55 [45-62] | 0.0-0.0% | 0.0-0.0% | 12-12 | 0.0-0.0% |

Note: Score entries retain the reported point score [lower-upper bound]; the point score is not necessarily the arithmetic interval midpoint. Frequency ranges are conditional on five score-interval scenarios. Leave-one-out results omit one other station under independent uniform sampling.

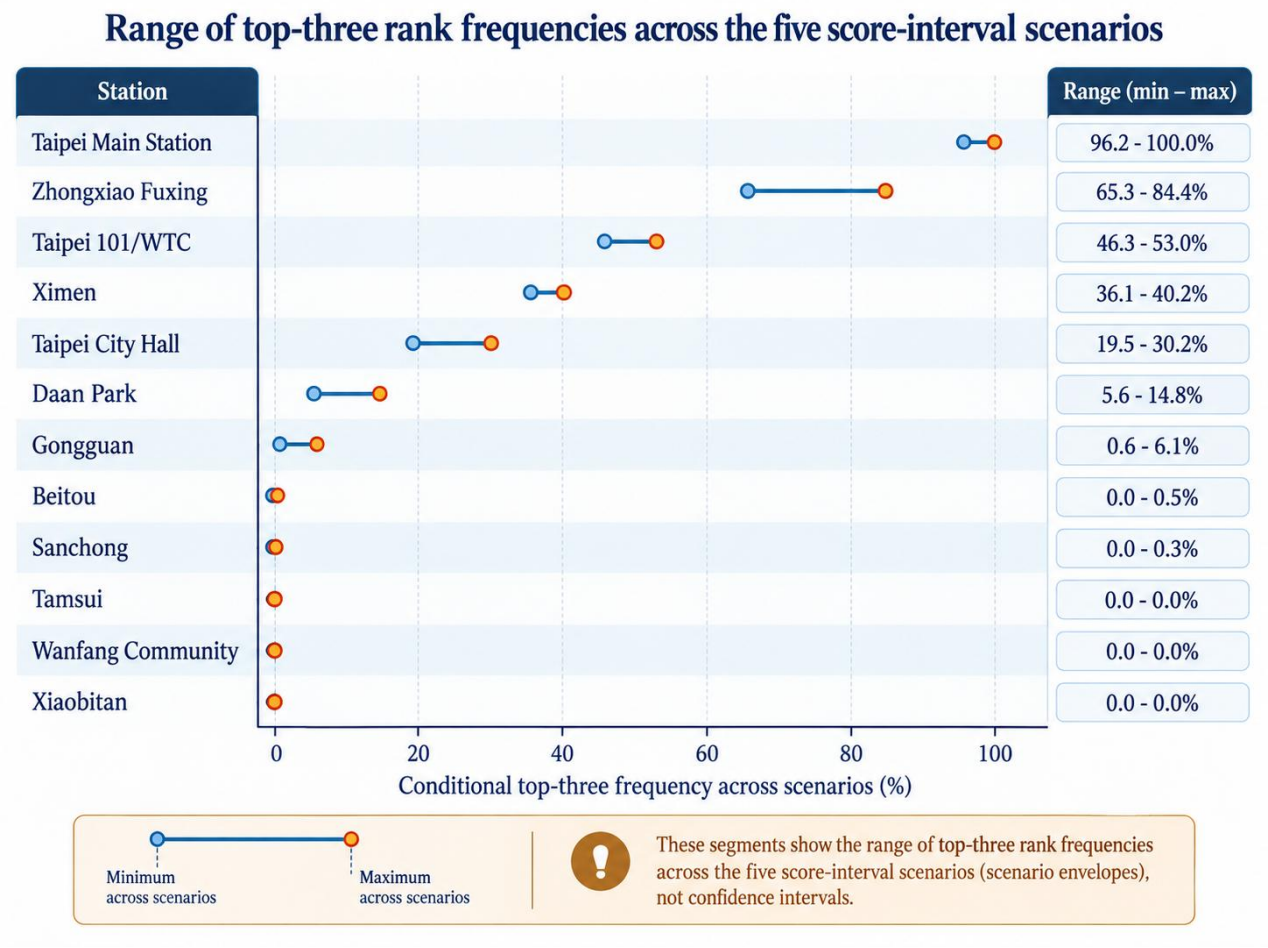



**Fig. 6** Range of top-three rank frequencies across five score-interval scenarios. Each segment joins the minimum and maximum percentages in Table 5. These scenario envelopes are not confidence intervals or population probabilities

### 4.5. Station-specific policy profiles reveal distinct geographies

The four profiles are presented as a multidimensional policy space rather than another ranking (Table 6; Fig. 7). Horizontal position represents peripheral-integration profile and vertical position represents local-activity profile. Marker area represents interface complexity, outline width represents access-exposure pressure, and marker shape identifies station type. The display keeps structural position, local context, interface burden, and passenger exposure analytically distinct.

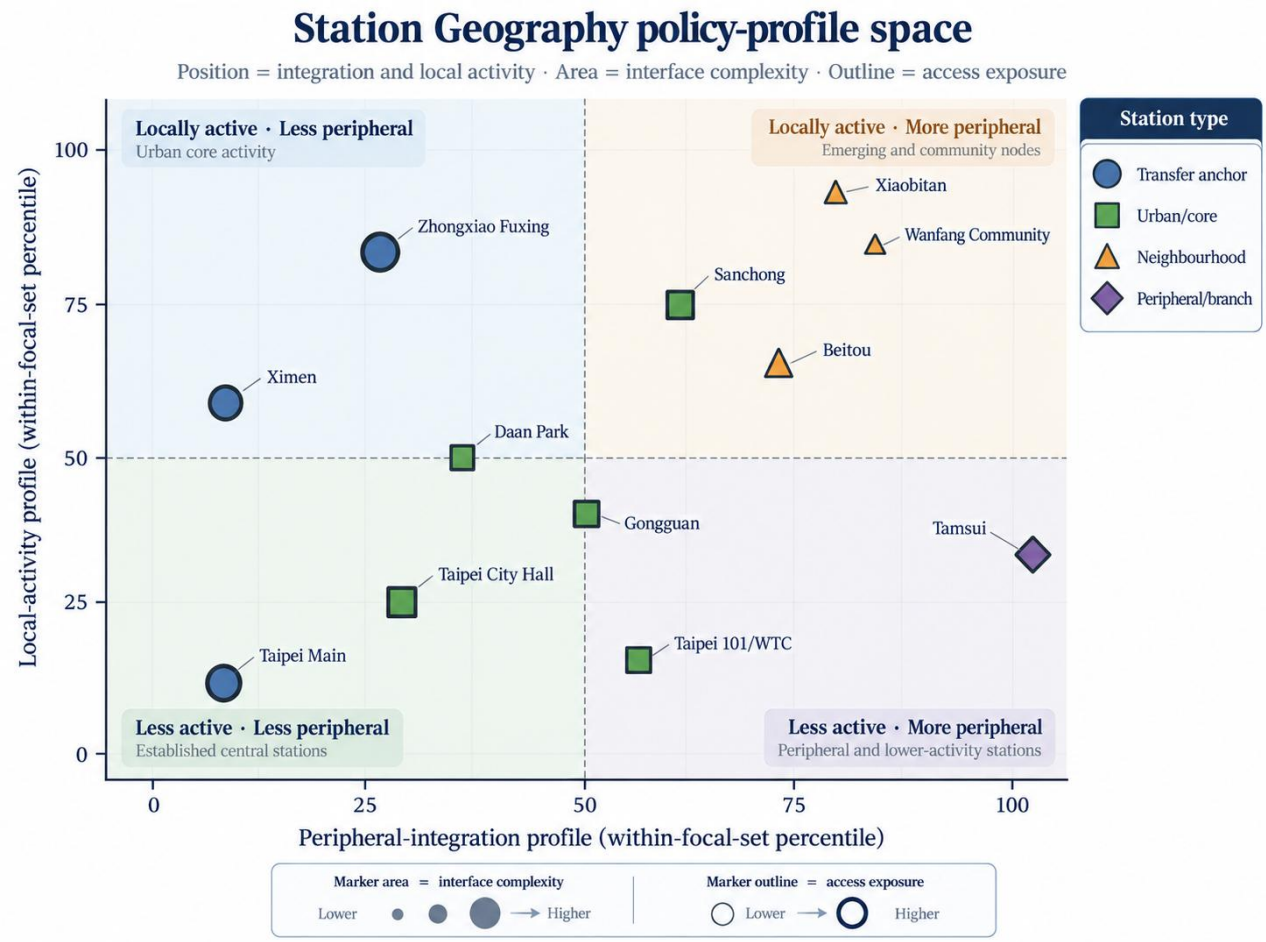
Taipei Main Station, Ximen, and Taipei City Hall occupy the central side of the space but display large markers and substantial outlines. Their principal concerns are interface complexity and passenger exposure rather than peripheral integration. Zhongxiao Fuxing combines similarly high interface and access pressure with an elevated local-activity profile, distinguishing it from a generic transfer-hub pattern. Taipei 101/WTC lies further toward integration need but lower on the local-activity axis, while Daan Park and Gongguan occupy transitional positions.

Beitou and Sanchong combine relatively high peripheral-integration and local-activity profiles, with different interface and access profiles. Wanfang Community and Xiaobitan are high on both positional axes but have smaller markers. Tamsui has the highest peripheral-integration percentile without a comparably high local-activity value. These are prompts for station-specific investigation, not direct measurements of unmet service need or development potential.

**Table 6. Station-specific policy-profile percentiles within the 12 focal stations.**

| Station | Access exposure | Interface complexity | Peripheral integration | Local activity profile | Dominant profile |
|---|---|---|---|---|---|
| Taipei Main Station | 100 | 100 | 8 | 8 | Access exposure + interface |
| Zhongxiao Fuxing | 92 | 92 | 25 | 83 | Access exposure + interface |
| Taipei 101/WTC | 42 | 67 | 58 | 17 | Interface complexity |
| Ximen | 75 | 83 | 17 | 58 | Interface complexity |
| Taipei City Hall | 83 | 75 | 33 | 25 | Access exposure |
| Daan Park | 50 | 50 | 42 | 50 | Mixed profile |
| Gongguan | 58 | 42 | 50 | 42 | Access exposure |
| Beitou | 17 | 58 | 75 | 67 | Peripheral integration |
| Sanchong | 67 | 33 | 67 | 75 | Local-activity evidence |
| Tamsui | 33 | 25 | 100 | 33 | Peripheral integration |
| Wanfang Community | 17 | 8 | 92 | 92 | Integration + local activity |
| Xiaobitan | 17 | 17 | 83 | 100 | Local-activity evidence |

Note: Percentiles describe relative positions within the focal set. Entrance accessibility designation is not a complete route-level accessibility measure, and the local-activity profile is not a direct estimate of development potential. Values support comparative diagnosis rather than causal or investment-return claims.




405 **Fig. 7** Station Geography policy-profile space for the 12 focal stations. Horizontal and vertical positions show peripheral-integration and local-activity percentiles; marker area represents interface complexity, outline width represents access exposure, and marker shape identifies station type. Dashed lines mark the 50th-percentile reference on each axis

## 5. Discussion

### 410 5.1. Separating metropolitan position from local diagnosis

The composite represents a broader Station Geography than a walkability label suggests. Its associations with closeness, demand, line count, metropolitan distance, and overlap place it within Taipei's node hierarchy. This is consequential for spatial analysis: geographical context is part of the construct being measured, rather than simply an external explanation of an otherwise independent
415 performance score.

A high-scoring interchange can also exhibit substantial access-exposure and interface-pressure proxies. Conversely, a lower-scoring neighbourhood or branch station can retain favourable entrance-accessibility indicators. Thus, a total score does not identify either the scale or the nature of an intervention. System importance, local conditions, and inclusive access need separate
420 interpretation.

Node-function residuals offer an additional descriptive comparison, but cannot be relabelled as pedestrian quality. They may reflect several included dimensions, omitted conditions, or measurement choices. Their role is to reveal departures from network alignment and direct attention back to component evidence, not to validate a new residual-based ranking.

### 5.2. From station buffers to shared spatial territories

The overlap results show why spatial attribution belongs within the interpretation of station indicators. At 800 m, 66.9% of Taipei's station areas have at least half of their territory shared with another station; at 1,200 m, the corresponding share is 92.4%. Larger radii increasingly represent corridor or district conditions rather than geographically exclusive station surroundings. This is evidence about territorial non-exclusivity, not observed route use or the number of residents counted more than once.

Different assessment tasks therefore imply different spatial units. Entrance safety relates to immediate paths and crossings; daily-needs access relates to routes from multiple entrances; land-use intensity and district amenities may require explicit shared-area or nearest-station attribution. These are alternative design choices suggested by the findings, not allocation methods evaluated in this study. Their appropriateness depends on the intervention and on whether shared opportunities should be attributed exclusively or jointly.

The focal set's greater overlap also cautions against transferring its score relationships directly to the network. Central stations can share both urban conditions and network importance. Future analysis should compare allocation rules while re-estimating the same indicators, separating a change in geographical attribution from a change in the population of stations being compared.

### 5.3. Station types as context for comparison

The primary core-network/local-peripheral partition captures systematic differences in demand, centrality, entrances, accessibility designation, and overlap. A single benchmark risks comparing structural roles rather than equivalent local conditions. Nevertheless, the modest silhouette coefficient means that these types summarise heterogeneous profiles rather than reveal sharply separated natural classes.

The exploratory four-type solution offers a finer vocabulary for diagnosis. Transfer anchors bring interface and passenger-exposure questions into view; urban destination/core stations draw attention to their surrounding public realm; neighbourhood-access and peripheral/branch stations raise different questions about everyday routes and network integration. The labels should guide investigation rather than prescribe the same intervention to every member.

Within-type benchmarking is a prospective application, not a model estimated here. With only 12 composite assessments, the present evidence supports contextual interpretation but not reliable type-specific performance thresholds. Extending the score matrix across the network would allow this implication to be tested without assuming that a low composite score necessarily calls for land-use intensification.

### 5.4. Conditional ranking uncertainty in spatial diagnosis

The sensitivity results separate a stable comparative conclusion from the numerical frequency attached to it. Taipei Main Station remains in the upper tier, although its first-rank frequency varies substantially. Several central stations have overlapping ranks, and their top-three frequencies change when the comparison set changes. Neither a fixed score nor a large number of draws makes the ordering assumption-free.

A diagnostic report can therefore present score bounds, broad comparative groups, and component gaps together. Where territorial conditions are shared, corridor-level interpretation may complement station-level reporting. However, the present analyses do not demonstrate that greater spatial overlap causes rank fragility: the geographical and interval experiments were conducted separately.

More draws reduce numerical sampling error under a specified scenario but do not resolve uncertainty about indicator measurement, geographical allocation, or expert priorities. Nor does the common-factor copula estimate spatial dependence between actual stations. These boundaries keep the sensitivity results informative without converting them into claims of real-world superiority.

### 5.5. Translating spatial evidence into differentiated diagnosis

Three distinctions organise the planning interpretation: network importance versus local deficiency; the spatial unit of measurement versus the spatial extent of an intervention; and comparative score stability versus evidence of project effectiveness. Table 6 and Fig. 7 retain these distinctions through separate profiles. They are a diagnostic input, not an optimised investment programme.

For Taipei Main Station and Zhongxiao Fuxing, high interface and access-exposure proxies point to questions about transfer routes and entrance accessibility. Tamsui's profile suggests examining feeder and network integration. Wanfang Community, Xiaobitan, Beitou, and Sanchong require different combinations of local-route, service, and integration evidence. Actual project selection would additionally require direct observations, costs, feasibility, and distributional assessment, none of which is estimated by the profile percentiles.

Population composition, accessibility services, demand, and environmental indicators provide only partial information about distribution. The present evidence does not establish outcomes for older or disabled users, low-income households, or people facing heat, rainfall, housing, or displacement pressures. These questions require group-specific exposure and access evidence rather than inference from an aggregate score.

### 5.6. Limitations and research implications

The expert-derived weights express priorities within this study, not universal parameters. Score-interval sampling does not replace assessment of expert-panel composition, indicator measurement, or normalisation choices. The composite must be interpreted through its component dimensions and stated bounds.

Entrance territories are Euclidean unions, not observed pedestrian catchments. They exclude gradients, barriers, crossings, passage opening hours, and route choice. The analysis also does not re-estimate all 18 indicators under each radius or jointly propagate spatial-boundary and score uncertainty. Route-network catchments and alternative allocation rules are therefore substantive extensions, not completed robustness tests.

Demand and topology refer to 2025, whereas entrance metadata were updated in June 2026. The study does not establish whether every entrance record was unchanged across those dates. Versioned inventories would strengthen temporal consistency and enable longitudinal comparison.

The composite assessment covers 12 purposefully selected stations. System-wide typology supplies context, but focal correlations, residuals, and rank frequencies are not network-wide estimates. Shared territories also caution against treating ordinary resampling intervals as spatially adjusted uncertainty. Wider score coverage and explicit dependence modelling would support stronger inference.

Demand and centrality measure activity and structure, not walking behaviour. Validation should use pedestrian counts, access-mode shares, observed paths, universal-access travel times, perceived walkability, and exposure-adjusted safety outcomes. Cross-city applications could test the framework's portability; they should not assume that Taipei's radii, weights, or type labels transfer unchanged.

## 6. Conclusion

This study uses Station Geography to connect spatial boundaries, network roles, and evaluation uncertainty in Taipei Metro. Its contribution is an integrated diagnostic interpretation of existing station-area concepts, supported by system-wide territorial analysis and a focal composite assessment.

Three findings anchor that interpretation. Entrance-based territories become highly non-exclusive at 800 and 1,200 m. The strongest tested station partition distinguishes core-network from local/peripheral roles, with an exploratory four-type interpretation. Within the focal set, composite scores align strongly with node function and demand, while score-interval analysis identifies greater stability in broad tiers than in exact middle ranks.

The applied spatial lesson is that a score acquires meaning through the area it represents and the stations against which it is compared. Explicit spatial attribution, context-sensitive comparison, and conditional uncertainty reporting provide a more informative basis for station-area diagnosis than a universal league table. The separate territorial and score analyses establish this interpretive need; demonstrating how boundary changes alter the same indicators and rankings remains a further empirical task.

## Data availability

The public station-flow and entrance datasets and operating-network sources are identified in the reference list. The derived study materials comprise the station indicator matrix, Grey-ANP weight intervals, network measures, multiscale territory metrics, typology outputs, and score-sensitivity results. The derived materials will be deposited in a public research repository, and the persistent identifier will be supplied to the journal when the repository record is released.

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