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Beyond Proximity: An LBS-Based Diagnosis of Planned–Used Life-Circle Mismatch in Lanzhou, China

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Abstract

Proximity-based planning provides a normative framework for organising everyday services, but local accessibility does not necessarily correspond to the spatial extent of observed destination use. Building on the distinction between normative proximity and grid-level aggregated revealed activity space, this study develops an LBS-based diagnostic framework for planned–used life-circle mismatch. Anonymised non-home, non-work home-grid–destination-grid links observed at least four times in aggregate during the month were analysed for 995 residential grids of 500 m × 500 m in Lanzhou, China. The framework evaluates five dimensions: boundary coverage, activity-space scale, centroid displacement, directional morphology, and destination environments, and translates them into four planning-diagnostic types. The results reveal widespread divergence between planned proximity and revealed use. On average, 82.0% of aggregated recurrent visit weight lies outside the corresponding 15 min walking boundary, while the median distance between residential and activity centroids is approximately 4.18 km. The outside-dominant pattern remains evident when the analysis is restricted to destinations located in selected basic-service-dominant POI environments. Greater local POI supply is generally associated with lower outside-boundary reliance, whereas bridge distance is more clearly associated with centroid displacement than with outside-boundary share. The explanatory models have modest fit and identify grid-level associations rather than causal behavioural mechanisms. These findings support treating the 15 min boundary as a normative benchmark for local service provision rather than a presumed container of residents’ daily activities. Planning evaluation should therefore combine accessibility standards with behavioural evidence and differentiated diagnosis. The LBS data do not identify trip purpose, travel mode, socioeconomic characteristics, service quality, or individual necessity, and the results should be interpreted as grid-level diagnostic associations.

Keywords: 15 min city; community life circle; activity space; planned–used mismatch; location-based service data; Lanzhou



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1. Introduction

Proximity-based planning has become a widely used response to the unequal distribution of everyday services. The 15 min city and the community life circle translate this ambition into an intuitive spatial proposition: residents should be able to reach essential facilities

within a short walk from home [1,2]. Chinese planning practice has institutionalised a similar logic through community life-circle standards, which encourage neighbourhood-scale provision and hierarchical facility allocation [3–5]. International evaluations operationalise proximity through several distinct traditions. Network catchments and cumulative-opportunity measures assess the quantity of reachable opportunities [6,7], population-coverage and equity measures assess who benefits from proximity [8,9], and composite readiness indices combine multiple dimensions of x-minute-city performance [10]. These approaches reveal where local provision is weak and where neighbourhood-scale intervention may be needed, but they do not by themselves establish where residents conduct recurrent daily activities.

A planned walking boundary is therefore interpreted here as a normative service benchmark: it identifies the area within which opportunities are expected to be available, but it does not demonstrate where residents actually conduct daily activities. This distinction is rooted in accessibility theory, which understands accessibility as the potential for interaction rather than realised interaction [11,12]. It is especially consequential in x-minute-city evaluation, where results depend on origins, networks, travel modes, thresholds, facility classifications, and POI sources [7,8,13,14]. Outside-boundary activity is treated as evidence of spatial divergence between normative proximity and revealed use, rather than as direct evidence of planning failure or resident disadvantage.

Activity-space research provides the conceptual basis for drawing this distinction. Daily urban experience is shaped by the set of places people encounter through routine movement rather than by a fixed residential container [15,16]. Kwan's work on the uncertain geographic context problem further shows that residential buffers and administrative units may poorly approximate the environments people actually experience [17,18]. This matters for life-circle evaluation because residents may travel beyond nearby facilities for very different reasons: local provision may be insufficient; higher-order or more specialised destinations elsewhere may be more attractive; social, work, care, or consumption routines may tie residents to non-local places; or urban form may displace accessible opportunities along particular corridors. Some outward activity may therefore reflect choice, complementarity, or access to specialised urban functions rather than deficiency. Treating the planned boundary as a self-contained behavioural unit risks conflating potential access with revealed use.

Evidence from diverse urban contexts indicates that proximity-based accessibility and observed destination use do not necessarily coincide [19–22]. These cases are not treated here as formally implemented x-minute cities. Rather, they demonstrate a more general analytical distinction: a home-based walking catchment represents potential reachability, whereas mobility records reveal which destinations are incorporated into recurrent activity patterns. The alignment between planned proximity and revealed activity should therefore be assessed empirically rather than inferred from walking catchments alone.

The issue is particularly salient in cities where urban form constrains the relationship between proximity and use. In corridor, river-valley, and topographically constrained cities, activity spaces may be shaped by local supply, linear development, bridge locations, cross-river connections, transport corridors, and the concentration of higher-order functions. Lanzhou is treated as a theoretically informative and methodologically revealing case of constrained urban morphology rather than as a statistically representative or uniquely extreme city. Its main built-up area is compressed into an elongated east–west valley corridor structured by the Yellow River, surrounding mountains, bridge nodes, and uneven urban expansion [23,24]. The city also has an explicit municipal 15 min life-circle planning basis: planning research and supporting-facility guidelines released in 2020 established a two-tier street–community framework for the central urban area [25–27]. This combination

provides a grounded normative reference and makes the potential divergence between proximity standards and activity geography especially visible.

Using location-based service data aggregated to residential grids, this study compares a normative 15 min walking catchment and an expanded 30 min sensitivity catchment with revealed activity spaces in Lanzhou, China. The analysis proceeds in three steps. It first measures the extent and morphology of planned–used mismatch through boundary coverage, spatial scale, centroid displacement, and directional indicators. It then develops a four-type diagnosis distinguishing neighbourhood anchoring, supply shortage with outside reliance, high local supply with outside reliance, and structural displacement. Finally, it examines whether outside destinations are associated with local deficiency, urban functional hierarchy, or river-valley spatial constraints by comparing destination environments and estimating explanatory models.

Three associational hypotheses are formally assessed in the empirical analysis. H1: Greater local facility supply within the planned 15 min boundary is associated with lower outside-boundary reliance, measured by OUT15 and OUT30. H2: Outside-boundary recurrent destinations are associated with denser and lower-diversity POI environments than inside-boundary destinations, indicating relative functional concentration at the aggregate POI-category level rather than identified individual preference. H3: River-valley structural proxies show clearer and more consistent associations with centroid displacement than with outside-boundary shares. These hypotheses concern grid-level statistical associations and are not tests of causal behavioural effects.

The primary contribution is conceptual–methodological: the study defines the alignment between normative proximity and revealed activity space as a distinct object of planning diagnosis. The five-dimensional framework operationalises this object, while the four-type typology translates different mismatch configurations into planning-relevant interpretations. The Lanzhou case demonstrates the application of this framework under a constrained river-valley morphology. Transferability concerns this analytical logic rather than the numerical results or classification thresholds, which require local recalibration.

The remainder of the paper is organised as follows. Section 2 reviews proximity planning, activity-space research, destination environments, and constrained urban morphology. Section 3 develops the conceptual framework. Section 4 describes the study area, data, indicators, diagnostic typology, and explanatory models. Section 5 presents the empirical results. Section 6 discusses the conceptual and planning implications and the study limitations, and Section 7 concludes.

2. Literature Review

2.1. Proximity Planning and the Behavioural Limits of Accessibility

The 15 min city and community life circle belong to a broader family of proximity-based planning approaches that seek to reorganise everyday service access around short-distance, low-carbon, and neighbourhood-scale living [1,2]. Their appeal lies in their legibility: by translating urban quality into a time-based proposition, they offer a communicable benchmark for judging whether essential services lie near residents' homes. This clarity has encouraged extensive empirical work measuring x-minute-city performance through network catchments, cumulative opportunities, walking accessibility, population coverage, readiness assessment, and composite indices [6–10]. In China, residential-area standards and community life-circle guidelines have embedded the same logic in the hierarchical allocation of public service facilities and walking-time thresholds [3–5].

Accessibility-based evaluation remains indispensable, identifying whether local opportunities exist, where spatial disparities concentrate, and which neighbourhoods may require additional provision. Yet accessibility measures potential reachability, not actual

use [11,12], and its planning meaning depends on how opportunities, origins, impedance, and evaluation thresholds are operationalised [28]. This distinction matters all the more because x-minute-city evaluations often rest on simplifying assumptions about origins, walking speeds, facility categories, network conditions, and time thresholds [7,8,13], and because their results can shift with POI data sources and facility classification [14,29]. Accessibility scores are therefore valuable planning indicators, but they cannot establish whether residents' daily activities are actually organised within planned walking catchments.

A further limitation concerns interpretation. The area reachable within 15 or 20 min is often treated, implicitly, as the expected scale of local living—and once the planned boundary is read as a behavioural container, activity beyond it is interpreted too quickly as evidence of local failure. Yet outward activity can arise from local insufficiency, functional hierarchy, destination specialisation, social routines, commuting chains, public transport connections, or individual preference. Recent critiques accordingly warn against a one-size-fits-all reading of proximity, particularly where service quality, affordability, temporal availability, population differences, and wider urban structure are not fully considered [13]. Proximity-planning evaluation must therefore separate normative service standards from revealed activity geographies.

2.2. Activity Spaces and Mobility-Aware Life-Circle Evaluation

The behavioural turn in x-minute-city research addresses this limitation directly. Instead of asking only what is available near the home, recent studies increasingly examine whether proximate opportunities correspond to observed destination use. Evidence from the United States, Nanjing, and Barcelona demonstrates partial rather than automatic correspondence between home-based accessibility and mobility patterns [19–22]. These settings are not treated as formally implemented x-minute cities; they provide empirical evidence for the broader distinction between potential reachability and revealed activity. This reframes life-circle evaluation from a supply-side question—what can be reached from home—to a relational one: how do planned catchments align with the activity spaces residents actually produce?

Activity-space and time-geography research [30] provides the theoretical bridge for this reframing, especially in community-life-circle studies that emphasise residents' daily practices rather than only facility catchments [31]. Activity space describes the set of locations individuals or groups encounter through daily routines, and has been used to examine social exclusion, exposure, and unequal access to urban opportunities [15,16,32]. Kwan's uncertain geographic context problem sharpens the point, showing that conclusions can change when people are assigned to spatial units that do not match their actual experienced environments [17,18,33]. The planned walking catchment is therefore meaningful as a planning standard, but cannot be assumed to represent the full geography of daily life. This study conceptualises the relationship between the planned catchment and the revealed activity space as planned–used mismatch—a multidimensional diagnostic condition rather than a single deficit.

2.3. Destination Environments, Constrained Morphology, and Research Gap

A central difficulty in interpreting planned–used mismatch is that outward reliance is not uniform. In some neighbourhoods, high outside-boundary activity may reflect weak local provision; in others, it may persist despite abundant local supply because residents are connected to higher-order centres, specialised services, employment routines, or larger consumption districts. Accessibility theory has long recognised that spatial access depends on the distribution of opportunities, transport conditions, and the interaction between land use and mobility [11,12]. In a planned–used diagnosis, destination environments therefore

add an interpretive layer: denser but lower-diversity outside destinations may signal specialised or higher-order functional concentrations, whereas distant outside destinations paired with weak local supply point more directly toward local deficiency.

The distinction matters for planning practice because the same outside-boundary share may call for different responses: local facility supplementation, public-transport integration, cross-boundary service coordination, quality improvement, or recognition of higher-order service networks. In the Chinese planning context, such differentiated and context-sensitive intervention is also consistent with the broader shift towards incremental and in-situ regeneration [34]. It becomes especially important under constrained urban morphology. In river-valley or corridor cities, services and movement may be channelled by linear development, crossings, and topographic constraints. Lanzhou is a theoretically informative case: its urban morphology has evolved around an elongated river-valley structure [23,35], municipal life-circle planning provides a local normative reference [25–27], and existing studies document uneven public-service provision and population–facility matching [24,36]. This evidence establishes the planning and morphological context, while leaving open the empirical question of whether recurrent non-home, non-work destinations align with planned walking catchments.

Three distinct gaps motivate this study. First, a conceptual gap remains because normative walking accessibility and revealed activity space are often treated as interchangeable representations of daily life, although they describe different spatial objects. Second, a diagnostic–methodological gap remains because existing approaches rarely distinguish the extent, spatial form, and possible contexts of divergence within one planning framework. Third, a contextual gap remains because constrained urban morphologies—including river-valley, cross-river, linear, and corridor-based cities—receive limited attention in mobility-aware life-circle evaluation. The study addresses these gaps by treating planned proximity and revealed activity space as related but distinct objects and by linking multidimensional mismatch measurement to differentiated planning diagnosis.

3. Theoretical Framework

A 15 min life circle and a revealed activity space represent two related but analytically distinct spatial objects. The former expresses a normative expectation of home-centred service reachability, whereas the latter records recurrent non-home, non-work activity geography. Their divergence is conceptualised as a relational condition between planned proximity and revealed use rather than as a single accessibility deficit. In this study, planned–used mismatch denotes the degree and spatial form of this divergence. Boundary crossing alone does not indicate planning failure or resident disadvantage; its planning meaning depends on the wider configuration of local supply, destination environments, activity-space morphology, and structural location.

This relational condition is examined through three conceptual layers. The first concerns the extent of mismatch, asking how strongly recurrent activity aligns with the normative boundary. The second concerns its spatial form, describing how revealed activity spaces extend, shift, or align relative to residential origins. The third concerns its interpretive context, examining whether divergence is associated with weak local provision, wider functional concentration, or river-valley structural constraints.

These layers are operationalised through five diagnostic dimensions: boundary coverage represents the extent of mismatch; activity-space scale, centroid displacement, and directional morphology represent its spatial form; and destination environments contribute to interpretive context, together with local-supply and structural variables. The primary contribution is therefore the joint evaluation of two spatial objects and the translation of

their relationship into differentiated, non-causal planning diagnoses. Detailed indicators and formulas are specified separately in Section 4.7.

4. Materials and Methods

4.1. Study Area

Lanzhou provides a locally grounded case for examining the relationship between proximity-based planning and revealed activity space (Figure 1). In 2020, the Lanzhou Municipal Natural Resources Bureau released planning research and supporting-facility guidelines that established a two-tier street–community 15 min life-circle framework for the central urban area. The framework reported 78 street-level life circles organised around a maximum 15 min walking range, while community-level circles focused on more frequently used facilities within approximately 5–10 min [25–27]. A subsequent municipal measure further formalised planning, construction, and management requirements for public-service facilities in the central urban area [37]. The city’s river-valley form—shaped by the Yellow River, surrounding mountains, linear transport infrastructure, bridge crossings, and peripheral clusters—makes the possible divergence between planned boundaries and activity spaces especially visible [23,24].

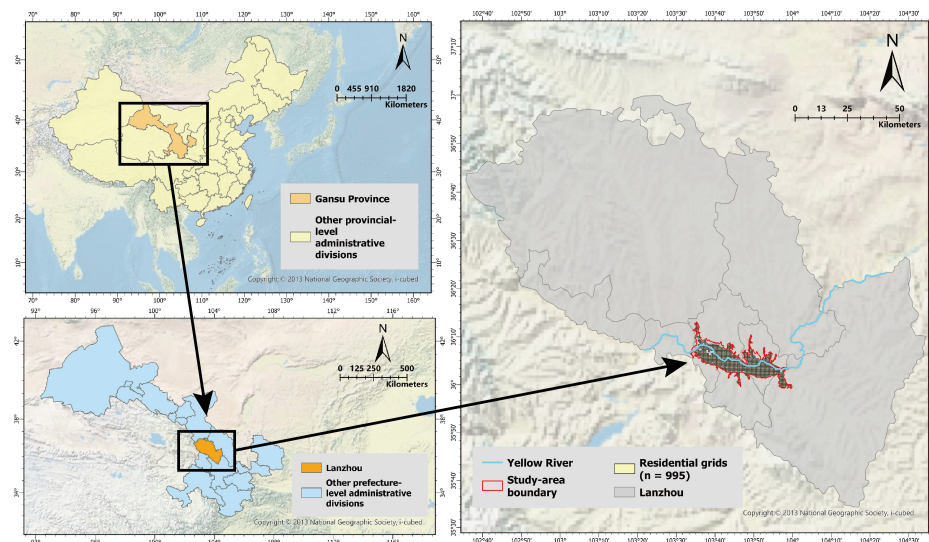


Figure 1. Study area and the spatial distribution of residential grids in Lanzhou.

The study does not assume that all official life circles or supporting facilities have been fully implemented, nor does it evaluate project-level plan delivery. Network-based 15 min walking isochrones are generated consistently from residential-grid origins to operationalise the locally articulated proximity principle. They serve as a normative benchmark but do not reproduce official life-circle polygons or constitute an audit of implementation compliance. “Planned” therefore denotes an operationalised normative planning standard. The analysis uses 500 m residential grids to integrate isochrones, POI supply, LBS destinations, and structural variables while reducing positional disclosure. The 995-grid primary sample supports boundary, typology, and model analysis; 962 grids support SDE-dependent indicators.

4.2. Data Sources

The empirical framework integrates walking isochrones, POI facilities, anonymised LBS destinations, activity-space morphology, and river-valley structural variables (Table 1). The table distinguishes the initial spatial pool, the 995-grid primary analytical sample, and the parallel subsamples used for SDE, destination–environment, service-context, and

threshold-sensitivity analyses. POIs serve as proxies for the spatial availability and aggregate functional composition of opportunities, while LBS records represent recurrent spatial links rather than trip purposes or individual behavioural motives [14,38–47].

Table 1. Data sources and analytical roles.

Data/Sample	Description	Sample Size	Analytical Role
Candidate grids and isochrones	500 m residential-grid centroids with valid 15 and 30 min Mapbox walking contours	1483 grids	Initial normative-boundary pool
LBS-valid grids	Candidate grids with at least one non-home, non-work activity-destination record	1065 grids	Input pool for recurrent-link filtering
Primary Core A2 sample	Home-grid–destination-grid links retained at aggregated monthly visit count ≥ 4	995 grids	OUT15/OUT30, centroid, typology, and baseline models
POI facilities	107,883 POIs in six aggregated categories	Study-area POIs	Local supply and destination context
SDE sample	At least three unique Core A2 destinations; two-standard-deviation ellipse	962 grids	Activity-space scale, elongation, and orientation
Paired destination environments	Both inside- and outside-boundary POI environments available	682 grids	Paired Wilcoxon and density/diversity contrasts
Service-context scopes	Broad and narrow POI-context filters	962/627 grids	Destination-scope robustness
Threshold sensitivity	Individual-user visit-count thresholds of ≥ 3 , ≥ 4 , and ≥ 5	1028/978/931 grids	Stability of the broad outside-boundary pattern
River-valley structure	Nearest of 166 bridge/tunnel points and edge-group flag	995 grids	Structural context and model covariates

Note: The 962-grid SDE sample, 682-grid paired destination–environment sample, and broad/narrow service-context samples are parallel branches from the 995-grid primary sample. The $\geq 3/\geq 4/\geq 5$ sensitivity reconstructions apply individual-user visit-count thresholds, whereas the primary Core A2 sample uses aggregate home-grid–destination-grid visit counts. The individual-user ≥ 4 grid set is fully contained within the primary sample; 17 grids occur only in the primary sample.

Walking isochrones were successfully generated for 1483 candidate residential-grid centroids; each had valid 15 and 30 min contours. The POI dataset contains 107,883 records in six aggregated categories. The LBS input comprises 129,552 anonymised user–destination records before recurrent-link filtering. River-valley context is represented by bridge distance and an edge-group flag; the bridge layer contains 166 bridge or tunnel points.

4.3. Data Processing

The LBS destination table draws on a one-month anonymised location-based service dataset for Lanzhou from 1 to 31 May 2025. Raw positioning records were processed upstream to identify stay episodes, which were subsequently consolidated into anonymised user–stay-location records. Home anchors were inferred from a regular nighttime presence (21:00–08:00) and work anchors from a regular weekday daytime presence (09:00–17:00). Candidate stay locations overlapping the inferred home or work anchors were removed, leaving anonymised non-home, non-work destination records with coordinates and visit counts. These records were aggregated to home-grid–destination-grid links for the main analysis, following established approaches for inferring important places and recurrent urban activity patterns [20,42,48].

Owing to privacy and data-use restrictions, raw LBS records, individual trajectories, and user-level coordinates cannot be disclosed. The reproducible units are the anonymised destination table and its grid-level aggregations. The dataset is treated as a behavioural sample for spatial diagnosis, with no claim to population representativeness. The records do not identify the trip purpose, travel mode, socioeconomic characteristics, preference, service quality, or whether an outside-boundary activity was necessary or discretionary [39].

For the main analysis, Core A2 retains a home-grid–destination-grid link when residents assigned to the same home grid made at least four visits in aggregate to the same destination grid during May 2025. The threshold is applied to the collective monthly link, not to each user. At the grid-pair level, four monthly visits approximate a collective recurrence of roughly once per week. It was therefore retained as a pragmatic intermediate cut-off that reduces the influence of very weak aggregate links while preserving sufficient spatial coverage; it is not treated as a universal behavioural threshold.

The reported sample sizes correspond to distinct stages and parallel branches. Of 1483 grids with valid isochrones, 418 lacked LBS activity-destination records, leaving 1065 grids. Excluding 70 grids without qualifying Core A2 links produced the 995-grid primary sample. Within it, 33 grids had fewer than three unique Core A2 destinations and were excluded from SDE estimation, leaving 962 SDE grids; 12 of the excluded grids had one destination and 21 had two, and none was excluded for collinearity or geometric degeneracy. A separate 313 grids lacked a valid inside or outside POI environment, leaving 682 grids for paired tests. Alternative individual-user visit-count thresholds of ≥ 3 , ≥ 4 , and ≥ 5 retained 1028, 978, and 931 grids. The individual-user ≥ 4 grid set is fully contained within the 995-grid primary sample; the 17 additional primary grids had no qualifying record under the individual-user re-filter (Supplementary Tables S1 and S2; Supplementary Figure S1).

The all-destination baseline describes the overall relationship between the normative boundary and recurrent non-home, non-work activity space. Broad and narrow destination–environment scopes provide secondary robustness checks. Each destination is classified by the dominant POI environment within 500 m: the narrow scope retains Healthcare and Living/Community Service environments, while the broad scope additionally includes Catering/Food, Shopping/Retail, and Sport/Leisure/Recreation. These scopes indicate the surrounding service context, not the purpose of the observed trip. OUT15 and OUT30 are recalculated under both scopes (Supplementary Tables S6–S8; Supplementary Figure S3).

4.4. Analytical Design

The analysis proceeds from boundary construction to mismatch diagnosis and explanatory modelling (Figure 2). The normative benchmark is represented by residence-based 15 min walking isochrones, with 30 min isochrones used as a sensitivity comparison; POI supply within these boundaries describes potential local provision. Grid-level aggregated revealed activity spaces are reconstructed from recurrent non-home, non-work destinations. The two spatial objects are then compared through boundary coverage, activity-space morphology, centroid displacement, directional orientation, and destination environments.

This design follows a relational logic. The planned boundary is a normative accessibility benchmark, whereas the revealed activity space represents aggregated recurrent activity geography. The analysis does not treat a 15 min catchment as a behavioural container and does not infer that every outside-boundary link is problematic. Planning interpretation is based on the joint configuration of mismatch intensity, local supply, destination context, activity-space form, and structural location [11,12,15–22].

The workflow contains five substantive steps. First, normative 15 and 30 min walking boundaries are generated from residential-grid centroids. Second, local supply and revealed

recurrent activity spaces are constructed. Third, planned–used mismatch is measured through OUT15, OUT30, scale, centroid, direction, and destination-context indicators. Fourth, a sequential rule assigns mutually exclusive diagnostic types. Fifth, paired tests and explanatory models assess the three hypotheses and support differentiated interpretation. The sample-flow strip distinguishes the 995-grid primary sample from the parallel SDE, destination–environment, and service-context branches. The workflow is diagnostic and associational rather than causal.

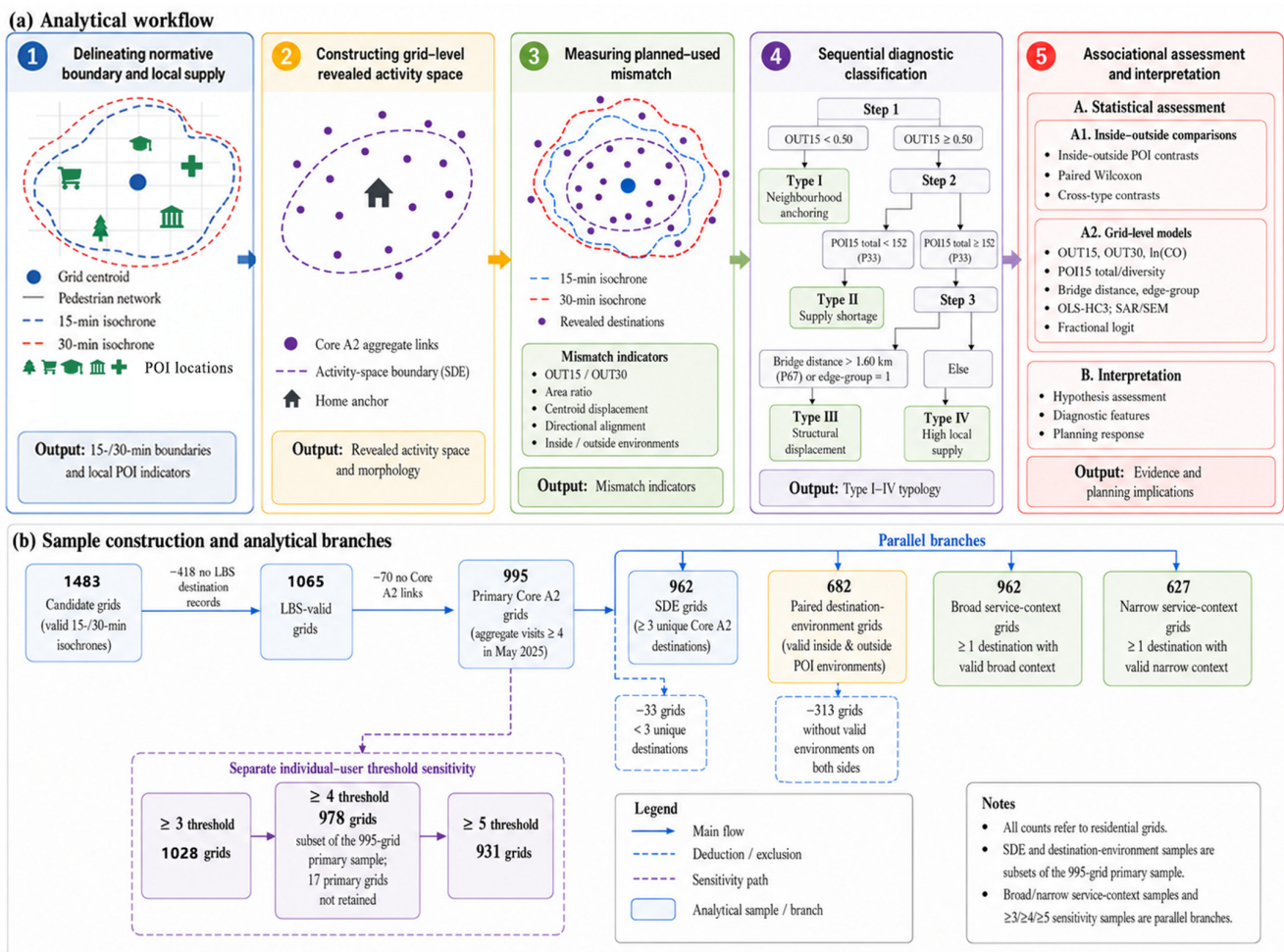


Figure 2. Analytical framework, sample branches, and sequential diagnostic workflow.

4.5. Normative Boundaries and Local Supply

Normative boundaries are walking-time isochrones generated from residential-grid centroids using the mapbox/walking routing profile of the Mapbox Isochrone API v1 (Mapbox, Inc., Washington, DC, USA) [32]. The 15 min isochrone is the primary benchmark, while the 30 min contour tests the sensitivity to the time threshold [1–9,13]. These contours provide standardised network-based planning benchmarks rather than exact experienced walking catchments. Grid-centroid origins and an incomplete representation of the slope, bridge-entry conditions, crossing delay, road hierarchy, gated access, informal paths, temporary barriers, and within-grid residential distribution may expand or contract practically experienced catchments and affect OUT15 and OUT30. The local POI supply is measured within the isochrones and interpreted as a potential opportunity rather than observed use [14,28,40].

The isochrones do not reproduce official life-circle polygons and should not be interpreted as a complete representation of residents' daily living areas. Their role is to

operationalise the locally articulated proximity principle consistently across residential-grid origins. The 30 min comparison addresses threshold sensitivity but does not resolve all origin and network uncertainty.

4.6. Revealed Activity-Space Morphology

The grid-level aggregated revealed activity space is reconstructed from Core A2 destination links. For each residential grid i , recurrent non-home, non-work destinations $j \in D_i$ are pooled and weighted by the aggregated visit count v_{ij} . The visit-weighted activity centroid c_i and centroid displacement CO_i are calculated using Equation (1):

$$c_i = \frac{\sum_{j \in D_i} v_{ij} x_j}{\sum_{j \in D_i} v_{ij}}, CO_i = \| c_i - h_i \| \quad (1)$$

In Equation (1), D_i is the set of recurrent Core A2 destinations linked to residential grid i ; v_{ij} is the aggregated visit count from grid i to destination j ; x_j is the projected coordinate vector of destination j ; h_i is the projected coordinate vector of the residential-grid centroid; c_i is the visit-weighted activity centroid; and CO_i is the Euclidean centroid offset. All coordinates are measured in the projected coordinate system EPSG:32648, and $\|\cdot\|$ denotes the Euclidean norm.

Standard-deviation ellipses (SDEs) are constructed for the 962 grids with at least three unique Core A2 destinations [49]. A two-standard-deviation ellipse is used to summarise spatial dispersion in EPSG:32648. The reported `sde_major_km` field is the semi-major axis, not the full major-axis length. The semi-major axis describes dominant extension, the semi-minor axis secondary dispersion, and the axis ratio elongation. These measures are sensitive to recurrent long-distance links and are treated as descriptive morphology rather than precise estimates of residents' daily activity-space size.

The SDE orientation is compared with an approximate east–west valley axis, yielding an alignment angle that runs from 0° (parallel to the valley axis) to 90° (a more north–south orientation). Because this axis is approximated by the east–west direction and not derived from a detailed geomorphological centreline, the angle is interpreted as an orientation tendency, a broad directional signal that does not constitute a precise morphological constraint (Table 2).

Table 2. Planned–used morphological gap indicators.

Dimension	Indicator	Definition	Main Interpretation
Coverage gap	$OUT_i^{15},$ OUT_{ii}^{30}	Visit-weighted share of Core A2 destination links outside the 15 and 30 min walking isochrones	Mismatch between the planned boundary and revealed activity space
Scale gap	$AR_i^{15},$ $\ln(AR_i^{15})$	SDE envelope area divided by the 15 min isochrone area, with log-transformed ratio used for skewed distributions	Revealed activity-space envelope relative to the planned boundary
Centroid gap	CO_i	Euclidean distance between the residential-grid centroid and the visit-weighted activity centroid	Displacement of recurrent activity centre
Directional gap	θ_i	Angle between the SDE major axis and the approximate east–west valley axis	Partial alignment with, or deviation from, the valley direction
Destination gap	$\Delta Density_i;$ ΔH_i	Outside-minus-inside difference in 500 m destination POI density and Shannon diversity	Functional environment of out-of-boundary destinations

4.7. Planned–Used Mismatch Indicators

Five groups of indicators measure planned–used relational morphology (Table 2). The first captures the coverage gap: the visit-weighted share of Core A2 destination links falling outside the x-minute walking isochrone. It is defined as OUT_i^x in Equation (2), with $x = 15$ or 30. A grid is outside-dominant when OUT_i^{15} is at least 0.5.

$$OUT_i^x = \frac{\sum_{j \in D_i} v_{ij} \mathbf{1}(j \notin ISO_i^x)}{\sum_{j \in D_i} v_{ij}}, x \in \{15, 30\} \quad (2)$$

In Equation (2), ISO_i^x denotes the x-minute walking isochrone generated from residential grid i , and $\mathbf{1}(\cdot)$ is an indicator function that equals 1 when destination j lies outside the corresponding isochrone and 0 otherwise. OUT_i^{15} and OUT_i^{30} are therefore visit-weighted outside-boundary shares rather than simple counts of destinations.

The second group captures the scale gap through AR_i^{15} , comparing the area of the normative 15 min walking isochrone with the SDE envelope of the revealed activity space. Because the resulting envelope-to-boundary ratios are strongly skewed, paper interpretation relies on their log transform and on median/IQR statistics.

The third group measures centroid displacement; the fourth, directional mismatch through SDE orientation and its alignment with the valley axis; the fifth, destination–environment mismatch, comparing the POI environment around inside- and outside-boundary destinations. Together, these indicators move the evaluation beyond a binary inside/outside statistic, describing how the revealed activity space departs from the planned boundary in scale, position, direction, and functional context.

4.8. Destination Environments

To examine how out-of-boundary destinations differ from inside-boundary destinations in their functional environments, each Core A2 destination is buffered by 500 m after projection to EPSG:32648. Within each buffer, surrounding POIs are counted and converted to density per square kilometre, and functional diversity is measured as the Shannon entropy of the six aggregated POI categories [50]. Density and diversity are calculated using Equation (3):

$$Density_{ij} = \frac{n_{ij}}{\pi r^2}, \quad H_{ij} = - \sum_{c=1}^6 p_{ijc} \ln p_{ijc}, \quad r = 0.5 \text{ km} \quad (3)$$

In Equation (3), n_{ij} is the number of POIs within the 500 m destination buffer around destination j linked to residential grid i . The buffer radius r is expressed as 0.5 km so that density is reported per square kilometre. H_{ij} is the Shannon diversity index of the six aggregated POI categories, p_{ijc} is the share of POIs in category c , and terms with $p_{ijc} = 0$ are treated as zero in the entropy calculation.

For every home grid, these measures are computed separately for destinations inside and outside the 15 min planned boundary, using the same link-level visit weights as the main revealed activity-space analysis. The inside–outside difference in density and diversity is retained as the central comparison (Table 2).

This procedure characterises the aggregate POI environment surrounding recurrent destinations. It does not identify trip purpose, travel mode, individual preference, service quality, or necessity. A Wilcoxon signed-rank test compares paired inside and outside environments at the grid level, and Kruskal–Wallis tests describe contrasts across the rule-based diagnostic types [51,52].

4.9. Diagnostic Typology and Threshold Sensitivity

Residential grids are assigned sequentially to four transparent, mutually exclusive diagnostic categories. First, grids with $OUT_{15} < 0.50$ are classified as neighbourhood anchoring. Among outside-dominant grids, those with POI_{15} total < 152 are classified as supply shortage with outside reliance; 152 is the 33rd percentile calculated with $q = 0.33$ in the 995-grid sample. Among the remaining grids, those with bridge distance > 1.60 km—the 67th percentile calculated with $q = 0.67$ —or edge-group = 1 are classified as structural displacement. All remaining outside-dominant grids are classified as high local supply with outside reliance. The categories are rule-based diagnoses rather than cluster-derived or causal neighbourhood classes. In these labels, “supply shortage” and “high local supply” refer to relatively low and high observed POI availability within this sample; they do not establish deficits or surpluses relative to population need, facility capacity, or service quality. Alternative P25/P75 and P40/P60 schemes reassign 11.8% and 10.3% of grids, respectively, indicating moderate sensitivity in individual assignments; however, the principal diagnostic contrasts and the ordering of types by median OUT_{15} remain broadly consistent (Supplementary Figure S2). The typology therefore requires local recalibration when transferred to other cities or datasets.

4.10. Statistical Modelling Strategy and Robustness Checks

Three baseline models are estimated for OUT_{15} , OUT_{30} , and logged centroid displacement. Covariates comprise POI_{15} total and diversity, bridge distance, and the edge-group flag. Bridge distance is the straight-line distance from each residential-grid centroid to the nearest of 166 bridge or tunnel points, calculated in EPSG:32648 and reported in metres. It is a coarse structural proxy rather than a measure of network crossing time, route impedance, bridge capacity, public-transport connectivity, slope-related cost, or actual cross-river travel cost. The edge-group flag is a binary indicator identifying grids assigned to predefined peripheral groups within the study area and likewise represents peripheral location coarsely. The OLS-HC3 specification is defined in Equation (4).

$$y_i = \beta_0 + X_i\beta + \varepsilon_i \quad (4)$$

In Equation (4), y_i is estimated separately as OUT_{15} , OUT_{30} , and $\ln(CO_i)$. For readable coefficient tables, POI_{15} total is reported per 1000 POIs and bridge distance per kilometre. HC3 robust standard errors reduce sensitivity to heteroskedasticity and finite-sample leverage [53]. The coefficients are interpreted as grid-level structural associations and not as causal effects on individual behaviour.

Spatial dependence is assessed using global Moran’s I on OLS residuals. SAR and SEM models use the same covariates and a row-standardised eight-nearest-neighbour weights matrix constructed from residential-grid centroids in EPSG:32648; no isolated units are present. These models are spatial robustness checks rather than alternative causal specifications.

Because OUT_{15} and OUT_{30} are fractional outcomes, OLS-HC3 is retained as a transparent baseline, with Breusch–Pagan tests and variance inflation factors reported as diagnostics [54]. Fractional-logit models with a quasi-binomial logit link provide robustness checks using the same covariates [55]. Together with the paired destination–environment tests, these analyses formally assess H1–H3: H1 from local-supply coefficients across OUT_{15} and OUT_{30} ; H2 from paired density/diversity contrasts; and H3 from the relative associations of bridge distance and edge-group location with boundary shares and centroid displacement.

5. Results

5.1. Extent of Boundary Mismatch

The comparison between walking isochrones and revealed activity spaces reveals widespread boundary mismatch across residential grids (Figure 3). Under the 15 min threshold, high OUT15 values are widespread across the river-valley urban belt, with most grids in the 0.60–0.80 or 0.80–1.00 classes (Figure 3a). Across the 995-grid main sample, the mean OUT15 is 0.820 and the median 0.846, and 94.9% of grids are outside-dominant, meaning that more than half of their recurrent non-home, non-work activity links fall beyond the 15 min planned boundary.

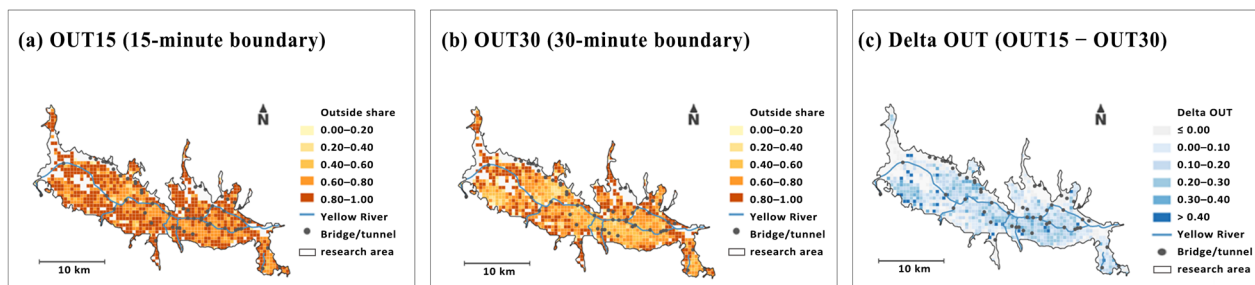


Figure 3. Spatial patterns of planned–used boundary mismatch under 15 and 30 min walking thresholds.

Expanding the threshold to 30 min eases the mismatch but leaves the pattern intact (Figure 3b). OUT30 shifts more grids into the intermediate classes, particularly along the central corridor and near several river-adjacent areas, yet high outside shares persist across much of the study area, including several peripheral branches and stretches of the elongated corridor. Across the same 995 grids, the mean OUT30 is 0.695, the median 0.694, and 82.6% of grids remain outside-dominant. The mismatch thus reflects more than an overly strict threshold: even a 30 min boundary does not fully correspond to residents' revealed routine activity spaces.

The reduction map sharpens the unevenness of this adjustment (Figure 3c). Where the decline from OUT15 to OUT30 is large, activities are located just beyond the 15 min boundary and are absorbed once the catchment expands. Where the decline remains limited, recurrent destinations lie beyond both thresholds. This scattered pattern of Δ OUT points to an uneven geography of mismatch: some neighbourhoods mainly face a problem of scale extension, while others show a more persistent separation between planned boundaries and revealed activity geographies.

The pattern persists under destination-context robustness checks. In the broad service-context scope, the mean OUT15 is 0.783, and 92.8% of 962 valid grids remain outside-dominant; the mean OUT30 is 0.630. The narrow scope retains 627 grids and yields a mean OUT15 of 0.846 and mean OUT30 of 0.690, but it is interpreted more cautiously because the destination sample is smaller and more selective (Supplementary Figure S3; Supplementary Tables S6–S8). These scopes classify surrounding POI environments rather than trip purposes, so the results show that boundary divergence persists under service-context filtering without establishing why individual trips occurred.

These results do not constitute a failure rate for the municipal life-circle programme or an audit of the 78 official life circles. They show divergence between a consistently operationalised normative benchmark and aggregated recurrent activity geography. The planning meaning of this divergence depends on local supply, destination context, morphology, and structural position rather than boundary crossing alone.

5.2. Morphology of Revealed Activity Spaces

Grid-level aggregated revealed activity spaces are spatially displaced from residential origins (Figure 4). The median home-to-activity centroid distance is approximately 4.18 km in the 995-grid sample. Larger offsets occur along portions of the elongated river-valley belt and peripheral branches, while some central-corridor areas record smaller offsets. Because trip purposes are unobserved, these patterns are interpreted as aggregate spatial links rather than individual behavioural mechanisms.

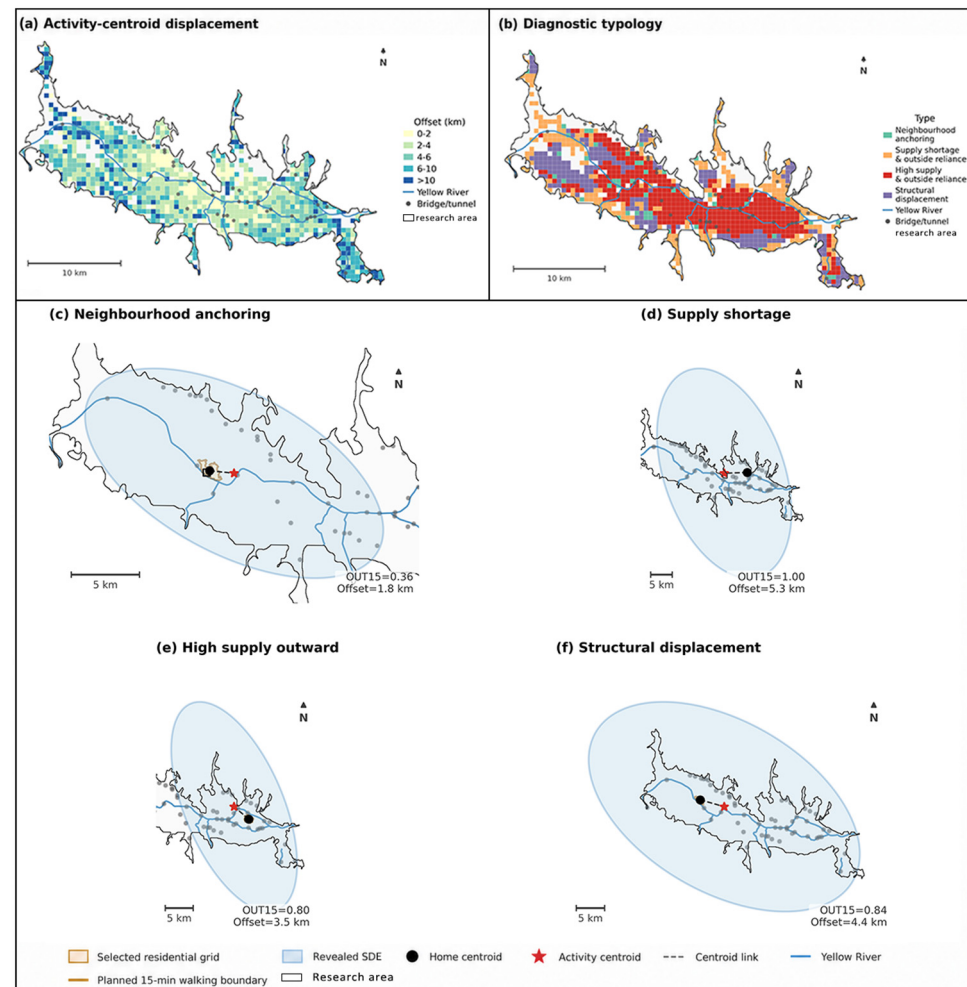


Figure 4. Revealed activity-space morphology and diagnostic types of planned–used mismatch.

The typology map synthesises this morphological variation (Figure 4b). Neighbourhood anchoring grids occupy only limited areas, while the other three types cover much larger portions of the study area. Supply shortage and outside reliance grids appear across several residential areas with relatively low observed POI availability. High local supply with outside reliance grids are more visible along parts of the main urban corridor. Structural displacement grids appear more often where revealed activity spaces are clearly separated from residential origins. Planned–used mismatch thus takes several distinct spatial forms across Lanzhou.

Representative cases illustrate these differences at the neighbourhood scale (Figure 4c–f). The neighbourhood anchoring case combines a low OUT15 of 0.36 with a short 1.8 km centroid offset, keeping the activity centroid close to its residential grid (Figure 4c). The supply shortage case lies at the opposite end, with complete outside dominance, where $OUT15 = 1.00$, and a 5.3 km centroid offset (Figure 4d). In the high local supply case, activities again extend beyond the planned boundary, though with a more moderate 3.5 km

offset (Figure 4e). The structural displacement case pairs a high OUT15 of 0.84 with a 4.4 km offset and a visibly elongated SDE (Figure 4f).

Across the three outside-dominant diagnostic types, group medians of the two-standard-deviation SDE semi-major axis range from 25.5 to 27.7 km, compared with 16.3 km for neighbourhood-anchoring grids. This range describes variation among group medians and is not a confidence interval. Semi-major-axis values may be influenced by recurrent long-distance links and are therefore interpreted as descriptive indicators of activity-space extension rather than precise estimates of residents' daily activity-space size.

5.3. Diagnostic Types of Planned–Used Mismatch

The sequential typology differentiates four planning-relevant conditions (Figure 4b; Table 3). High local supply with outside reliance is the largest group, with 398 grids (40.0%). Its median OUT15 of 0.795 indicates that substantial outward activity can coexist with comparatively high observed local POI availability. This pattern is consistent with connection to wider urban functional concentrations, but the LBS data do not identify preference, attraction, or trip purpose.

Table 3. Diagnostic typology, selected indicators, and indicative planning responses.

Type	<i>n</i> (%)	Decision Rule	Selected Diagnostic Profile	Diagnostic Interpretation	Indicative Planning Response
Neighbourhood anchoring	51 (5.1%)	OUT15 < 0.50	OUT15 0.333; offset 2.64 km; POI15 256	Recurrent activity is comparatively aligned with the normative boundary.	Maintain local service quality and monitor emerging gaps; avoid assuming full self-containment.
Supply shortage with outside reliance	307 (30.9%)	OUT15 $\geq$ 0.50 and POI15 < 152	OUT15 1.000; offset 5.97 km; POI15 52	Relatively low observed POI availability coincides with extensive outward reliance and displacement.	Prioritise essential local facilities, small public spaces, and service-quality assessment.
Structural displacement	239 (24.0%)	OUT15 $\geq$ 0.50; POI15 $\geq$ 152; bridge > 1.60 km or edge = 1	OUT15 0.842; offset 4.80 km; bridge 1957 m	Peripheral or crossing-constrained location is associated with displaced activity space.	Coordinate facility allocation with bridge, transit, and cross-river accessibility improvements.
High local supply with outside reliance	398 (40.0%)	Remaining outside-dominant grids	OUT15 0.795; offset 3.45 km; POI15 1082	Outward reliance persists despite relatively high observed POI availability, consistent with wider functional concentration.	Retain basic local provision and improve links to higher-order centres rather than duplicate all functions locally.

Note: Values are medians. The decision rule is sequential. SDE values use valid ellipses only. The alternative P25/P75 and P40/P60 schemes reassign 11.8% and 10.3% of grids, respectively, while preserving the principal diagnostic contrasts. Interpretations and responses are indicative rather than prescriptive because trip purpose, service quality, preference, and individual necessity are not observed.

Supply shortage with outside reliance includes 307 grids (30.9%) and records the highest median OUT15 (1.000) and median centroid displacement (5.97 km). The joint pattern of relatively low observed POI availability, extensive outside-boundary reliance, and greater displacement makes limited local availability a plausible planning concern, while remaining a diagnosis rather than proof that specific trips were caused by unmet needs.

Structural displacement includes 239 grids (24.0%). It combines high outside-boundary reliance with a greater bridge distance and clearer separation between residential and activity centroids. Bridge distance is a coarse proxy, so the type indicates the association with a peripheral or crossing-constrained location rather than measured network impedance or actual cross-river travel cost.

Neighbourhood anchoring is the smallest group, with 51 grids (5.1%). These grids have $OUT_{15} < 0.50$ and shorter centroid displacement, indicating closer alignment between recurrent activity and the normative boundary. This does not imply complete self-containment or superior implementation; it identifies a comparatively local pattern within the present sample.

Individual grid assignments are moderately threshold-sensitive: the P25/P75 and P40/P60 alternatives reassign 11.8% and 10.3% of grids. Nevertheless, the main diagnostic contrasts remain broadly consistent: supply-shortage grids retain the weakest local provision and highest outside-boundary reliance, structurally displaced grids retain greater bridge distances and centroid displacement, and the ordering of types by median OUT_{15} is unchanged (Supplementary Figure S2). The typology is therefore a transparent, locally calibrated diagnostic tool rather than a fixed classification.

5.4. Functional Environments of Outside Destinations

Destination environments add diagnostic evidence on the contexts associated with locations beyond the boundary (Table 4). Across 682 paired grids, the median POI density is 853.75 outside and 466.78 inside the 15 min boundary; 71.0% of paired grids have higher outside density. Paired Wilcoxon tests confirm the higher outside density ($W = 63,175, p < 0.001$) and lower outside diversity ($W = 25,302, p < 0.001$; Supplementary Table S5). These findings support H2 at the aggregate POI–environment level.

Table 4. Outside and inside destination POI environments by diagnostic type.

Type	Outside Density Median	Inside Density Median	Density Diff. Median	Outside Diversity Median	Dominant Outside POI Type
High local supply with outside reliance	1060.63	734.98	194.40	1.272	Shopping services
Supply shortage and outside reliance	529.99	63.57	561.75	1.186	Shopping services
Structural displacement	745.85	415.31	284.07	1.216	Shopping services
Neighbourhood anchoring	959.97	259.23	384.29	1.380	Shopping services

Note: Values are visit-weighted grid-level medians. Inside and outside destinations are defined relative to the 15 min walking isochrone. POI density is measured within 500 m buffers around Core A2 destinations.

The combination of higher density and lower Shannon diversity is interpreted as relative functional concentration at the aggregate category level. It may reflect dominance by one category—especially shopping services—but, because trip purposes are unobserved, it is interpreted at the aggregate destination–environment level. High local supply with outside reliance is therefore consistent with an urban-hierarchy interpretation, while remaining diagnostic rather than behavioural or causal.

Supply-shortage and structural-displacement grids remain diagnostically distinct. For the former, weak local provision is the immediate planning concern; for the latter, the location and reachability of opportunities also matter. Kruskal–Wallis tests describe cross-type contrasts but do not independently validate categories that were constructed partly from the same variables (Supplementary Table S5).

5.5. Explanatory Models and Robustness Checks

The explanatory models provide an associational assessment rather than a causal account (Table 5). Greater local POI supply is significantly associated with lower OUT_{15} ,

lower OUT30, and shorter logged centroid displacement, supporting H1. An additional 1000 POIs within the 15 min boundary is associated with a 0.029 lower OUT15, a 0.044 lower OUT30, and a 0.070 lower logged centroid offset in the OLS-HC3 baseline. Bridge distance is not clearly associated with OUT15 or OUT30 but is positively associated with logged centroid displacement: each additional kilometre is associated with a 0.114 higher logged offset. H3 is therefore partially supported: structural proxies relate more clearly to displacement than to the boundary share.

Table 5. OLS–HC3 estimates and spatial-model robustness checks.

Variable/Statistic	M1: OUT15	M2: OUT30	M3: ln(Centroid Displacement)
POI15 total (per 1000 POIs)	−0.029 *** (0.003)	−0.044 *** (0.004)	−0.070 *** (0.012)
POI15 diversity (Shannon entropy)	−0.010 (0.006)	−0.025 *** (0.006)	−0.043 ** (0.013)
Bridge distance (km)	−0.005 (0.008)	0.013 (0.009)	0.114 *** (0.023)
Edge-group flag	0.020 (0.017)	0.016 (0.020)	0.109 * (0.050)
Constant	0.922 *** (0.046)	0.888 *** (0.053)	1.866 *** (0.108)
N	995	995	995
R ²	0.075	0.149	0.108
Adjusted R ²	0.071	0.146	0.105
OLS AIC	−580.52	−251.14	1792.88
Selected spatial model	SEM	SAR	SAR
Selected spatial-model AIC	−592.15	−293.39	1698.60
Spatial parameter	$\lambda = 0.207$ ***	$\rho = 0.343$ ***	$\rho = 0.460$ ***

Note: Entries for M1–M3 are OLS coefficients with HC3 robust standard errors in parentheses. * $p < 0.05$, ** $p < 0.01$, and *** $p < 0.001$. POI15 total is scaled per 1000 POIs, bridge distance is reported in kilometres, and POI15 diversity is measured using Shannon entropy. The edge-group flag equals 1 for grids whose centroids are located within 500 m of the study-area boundary. The reported spatial model is the lower-AIC specification among SAR and SEM; λ denotes the spatial-error coefficient and ρ the spatial-lag coefficient. Model fit is modest. The spatial-model results are used as robustness checks and should not be interpreted as causal behavioural effects.

Bridge distance remains a coarse structural proxy and does not measure network travel time, route impedance, bridge capacity, public-transport connectivity, slope-related cost, or actual cross-river travel cost. Its clearer association with centroid displacement than with OUT15 or OUT30 supports only a limited structural interpretation. The edge-group flag is weaker: it is significant only in the OLS centroid model and becomes non-significant in SAR and SEM checks.

Diagnostics indicate low multicollinearity, heteroskedastic residuals, and spatial dependence, supporting HC3 standard errors and spatial checks (Supplementary Tables S3 and S4). Fractional-logit results reinforce the negative local-supply association under the all-destination and broad service-context scopes. The narrow scope produces a sign reversal for OUT15 in a much smaller and selected sample and is therefore auxiliary rather than the principal robustness basis (Supplementary Table S8). Given the modest explanatory power, the models identify structural associations rather than causal behavioural mechanisms.

Taken together, H1 is supported, H2 is supported at the aggregate destination–environment level, and H3 is partially supported. Local provision, functional concentration, and structural displacement relate to different dimensions of mismatch and should therefore be analysed separately.

6. Discussion

6.1. From Proximity Standards to Behavioural Alignment

The central contribution reaches beyond the observation that many activities occur outside a 15 min boundary. A planned life circle and a revealed activity space are different analytical objects: the former expresses a normative expectation of proximate service reachability, whereas the latter records aggregated recurrent activity geography. Planned–used mismatch is the relational condition between them, not a direct measure of programme failure, resident disadvantage, or behavioural non-compliance [11,12,17].

This distinction extends accessibility evaluation without displacing it. Facility counts and walking isochrones remain necessary for assessing neighbourhood opportunity; behavioural evidence adds a second layer, showing whether nearby opportunities correspond to patterns of use and, where they diverge, what spatial form and context the mismatch takes [20]. The planning question shifts from whether activity is contained to how normative provision and revealed use align.

The contribution is deliberately diagnostic. Aggregated LBS links do not identify trip purpose or individual motivations. Outside-boundary activity may reflect local insufficiency, higher-order functions, social or care relations, travel chains, or individual choice. Interpretation therefore relies on the combined evidence of supply, destination context, morphology, and structural location.

6.2. Distinguishing Deficiency, Hierarchy, and Structural Displacement

The four-type diagnosis separates pathways often collapsed into a single accessibility deficit [9,12,20]. Supply shortage with outside reliance is the type for which a local-deficiency interpretation is most plausible. Its combination of relatively low observed POI availability, high outside-boundary reliance, and greater centroid displacement suggests that a limited nearby opportunity set may contribute to recurrent outward activity. This is consistent with the negative local-supply coefficients for OUT15, OUT30, and centroid displacement. Because trip purpose, service quality, preference, and individual necessity are unobserved, the pattern remains a planning diagnosis rather than evidence that specific trips were caused by unmet local needs. High local supply with outside reliance shows a different pattern: external destinations are denser and lower in diversity at the aggregate category level, which is consistent with urban functional concentration without proving preference or attraction.

Structural-displacement grids require a third reading. Bridge distance is associated more clearly with centroid displacement than with OUT15 or OUT30, so H3 is only partially supported. River-valley structure may reshape the distance and direction of activity spaces without determining whether a fixed walking boundary is crossed [23,24]. The typology itself is threshold-dependent: alternative schemes reassign a moderate share of grids, although the principal diagnostic contrasts remain broadly consistent. It should therefore be used as a transparent, locally calibrated planning tool rather than a fixed neighbourhood classification.

6.3. Planning Implications for Differentiated Life-Circle Policy

Life-circle policy should retain proximity standards while adding behavioural diagnosis [3,5,9,20]. Table 3 links each type to an indicative response. For supply-shortage grids, the priority is to strengthen essential local facilities, including daily retail, primary healthcare, community services, and small public spaces. For high-supply outside-reliance grids, basic local provision should be maintained while pedestrian, cycling, and transit connections to higher-order centres are improved, rather than duplicating every specialised function locally.

For structural-displacement grids, facility planning should be coordinated with bridge access, cross-river connections, bridgehead service nodes, transit interchange, and corridor-based micro-renewal. The 15 min benchmark has different practical meanings across an uneven river-valley landscape, and walking-isocrone evaluation should be read together with crossing and network conditions [6,8,19,56]. These responses remain indicative because the data do not observe purpose, mode, service quality, or individual necessity.

Success should therefore be judged by whether local essentials are accessible, whether avoidable deprivation contributes to outward reliance, and whether residents have workable connections to wider urban opportunities—not by minimising every journey beyond the neighbourhood. Neighbourhood anchoring likewise calls for maintaining and monitoring local service quality rather than assuming complete self-containment.

Lanzhou is a theoretically informative and methodologically revealing case, not a statistically representative or uniquely extreme city. The analytical logic—separating planned proximity from revealed activity space and moving from mismatch measurement to differentiated diagnosis—is transferable to river-valley, mountainous, cross-river, linear, and corridor-based cities. Numerical thresholds, service categories, time standards, and policy responses must be recalibrated to local planning systems, data quality, and mobility conditions.

6.4. Limitations and Future Research

Several limitations warrant acknowledgement. First, the LBS dataset supports grid-level diagnosis of aggregated recurrent spatial links but cannot identify the trip purpose, travel mode, socioeconomic profile, preference, service quality, or whether an outside activity is necessary or discretionary [39,41,43]. Mobile positioning data also involve ownership, sampling, and positional uncertainty and should be treated as a behavioural sample rather than a population-representative panel [20,43,57,58]. The all-destination baseline is appropriate for describing overall recurrent activity geography but may include shopping, leisure, medical, social, and higher-order destinations. Broad and narrow service-context slices partly address this scope issue, but they classify surrounding POI environments rather than observed trip purposes [40,43].

Second, methodological choices are operational rather than definitive. The main Core A2 threshold is an aggregate home-grid–destination-grid criterion for May 2025, whereas the $\geq 3/\geq 4/\geq 5$ sensitivity reconstructions use individual-user visit-count thresholds. They support the stability of the broad pattern but do not reproduce the 995-grid sample one-to-one; the individual-user ≥ 4 grid set is fully contained within the primary sample, with 17 grids retained only by the aggregate grid-pair criterion. The typology is moderately threshold-sensitive and requires local calibration. The OLS-HC3, fractional-logit, SAR, and SEM models have modest explanatory power and identify associations rather than causal effects [53,55]. Bridge distance and the edge-group flag are coarse proxies. SDEs, 500 m grids, and grid-centroid isochrones simplify network travel time, bridge-entry conditions, crossing delays, slope, gated access, within-grid residential distribution, temporal rhythms, and scale effects [15,16,49,59–61].

Future research should test alternative grid scales, origin perturbation, building- or entrance-level origins, locally calibrated pedestrian networks, slope impedance, crossing delays, weekday–weekend and daytime–evening variation, trimmed activity spaces, and core-destination clustering. Additional covariates—public-transport accessibility, road-intersection density, slope, land-use intensity, housing price, and socioeconomic proxies—could better distinguish shortage, centrality, and peripheral disadvantage. Comparative work across compact, polycentric, mountainous, river-valley, and transit-oriented cities

should evaluate which relationships travel across contexts and how thresholds and typologies should be recalibrated.

7. Conclusions

This study examined the alignment between an operationalised municipal 15 min life-circle benchmark and grid-level aggregated revealed activity spaces in Lanzhou. The city has an explicit two-tier life-circle planning framework, but the analysis does not assume that all 78 official life circles or their supporting facilities have been fully delivered and does not reproduce official planning polygons. Across the 995-grid sample, most repeatedly observed aggregate non-home, non-work visit weight lies outside the 15 min benchmark, and activity spaces are often extended and displaced. Destination-context robustness checks show that the pattern persists under destination–environment filtering, while still not identifying the trip purpose.

The primary contribution is conceptual–methodological: normative proximity and revealed activity space are treated as different spatial objects whose alignment requires joint evaluation. The five-dimensional framework captures the mismatch extent, spatial form, and interpretive context, and the threshold-dependent four-type typology translates these configurations into differentiated planning diagnoses. H1 is supported, H2 is supported at the aggregate POI–environment level, and H3 is partially supported. The models have a modest fit and provide grid-level associations rather than causal behavioural explanations.

For planning practice, proximity standards should be retained but evaluated alongside behavioural evidence. Local essentials should be strengthened where provision is weak; connections to higher-order centres should be improved where a strong local supply coexists with outward reliance; and facility allocation should be coordinated with bridge and transit accessibility where displacement is structurally associated. The aim is not to contain every activity within 15 min, but to distinguish avoidable local deficiency from wider functional connection and a constrained spatial structure.

Supplementary Materials: The following supporting information can be downloaded at <https://www.mdpi.com/article/10.3390/land15081341/s1>: Table S1: Sample construction, Core A2 definitions, and analytical subsets; Table S2: Core A2 threshold sensitivity; Figure S1: Core A2 threshold sensitivity: distribution of outside-boundary shares; Table S3: Baseline model diagnostics and spatial-model comparison; Table S4: Full SAR and SEM coefficients for baseline models; Table S5: Statistical tests for destination environments and diagnostic typology; Figure S2: Typology sensitivity under alternative classification threshold schemes; Figure S3: Distribution of OUT15 under three destination-scope definitions; Table S6: Robustness check of outside-boundary shares under basic-service destination scopes; Table S7: Diagnostic typology comparison under basic-service destination scopes; Table S8: Fractional-logit robustness checks for outside-boundary shares; Table S9: LBS spatial-coverage audit; Data S1: Category mapping for basic-service destination scopes.

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Data Availability Statement: Aggregated summary tables, model diagnostics, robustness checks, and category mappings supporting the reported findings are provided in the Supplementary Materials. The raw LBS-derived mobility records are not publicly available due to privacy, legal, and third-party data-use restrictions. De-identified grid-level indicators used to reproduce the main tables and figures may be made available from the corresponding author upon reasonable request, subject to permission from the data provider.

Conflicts of Interest: The authors declare no conflicts of interest.

References

- Moreno, C.; Allam, Z.; Chabaud, D.; Gall, C.; Pratlong, F. Introducing the “15-Minute City”: Sustainability, Resilience and Place Identity in Future Post-Pandemic Cities. *Smart Cities* **2021**, *4*, 93–111. [\[CrossRef\]](#)
- Omwamba, J.; Rotaris, L.; Longo, G. An Assessment of Proximity in the 15-Minute City: A Systematic Literature Review. *Urban Transit.* **2025**, *3*, 100012. [\[CrossRef\]](#)
- GB 50180-2018; Standard for Urban Residential Area Planning and Design. China Architecture & Building Press: Beijing, China, 2018.
- General Office of the Ministry of Commerce; General Office of the National Development and Reform Commission; General Office of the Ministry of Civil Affairs; General Office of the Ministry of Finance; General Office of the Ministry of Human Resources and Social Security; General Office of the Ministry of Natural Resources; General Office of the Ministry of Housing and Urban-Rural Development; General Office of the Ministry of Culture and Tourism; General Office of the State Administration for Market Regulation; General Office of the China Banking and Insurance Regulatory Commission; et al. In *Guidelines for the Construction of Urban 15-Minute Community Life Circles*; Ministry of Commerce of the People’s Republic of China: Beijing, China, 2021.
- TD/T 1062-2021; Technical Guidelines for Community Life-Circle Planning: TD/T 1062-2021. Ministry of Natural Resources of the People’s Republic of China: Beijing, China, 2021.
- Logan, T.M.; Hobbs, M.H.; Conrow, L.C.; Reid, N.L.; Young, R.A.; Anderson, M.J. The X-Minute City: Measuring the 10, 15, 20-Minute City and an Evaluation of Its Use for Sustainable Urban Design. *Cities* **2022**, *131*, 103924. [\[CrossRef\]](#)
- Papadopoulos, E.; Sdoukopoulos, A.; Politis, I. Measuring Compliance with the 15-Minute City Concept: State-of-the-Art, Major Components and Further Requirements. *Sustain. Cities Soc.* **2023**, *99*, 104875. [\[CrossRef\]](#)
- Sdoukopoulos, A.; Papadopoulos, E.; Verani, E.; Politis, I. Putting Theory into Practice: A Novel Methodological Framework for Assessing Cities’ Compliance with the 15-Min City Concept. *J. Transp. Geogr.* **2024**, *114*, 103771. [\[CrossRef\]](#)
- Weng, M.; Ding, N.; Li, J.; Jin, X.; Xiao, H.; He, Z.; Su, S. The 15-Minute Walkable Neighborhoods: Measurement, Social Inequalities and Implications for Building Healthy Communities in Urban China. *J. Transp. Health* **2019**, *13*, 259–273. [\[CrossRef\]](#)
- Carvalho, T.; Farber, S.; Manaugh, K.; El-Geneidy, A. Assessing the Readiness for 15-Minute Cities: A Literature Review on Performance Metrics and Implementation Challenges Worldwide. *Transp. Rev.* **2025**, *45*, 801–827. [\[CrossRef\]](#)
- Hansen, W.G. How Accessibility Shapes Land Use. *J. Am. Inst. Plan.* **1959**, *25*, 73–76. [\[CrossRef\]](#)
- Geurs, K.T.; Van Wee, B. Accessibility Evaluation of Land-Use and Transport Strategies: Review and Research Directions. *J. Transp. Geogr.* **2004**, *12*, 127–140. [\[CrossRef\]](#)
- Mouratidis, K. Time to Challenge the 15-Minute City: Seven Pitfalls for Sustainability, Equity, Livability, and Spatial Analysis. *Cities* **2024**, *153*, 105274. [\[CrossRef\]](#)
- Rahman, F.; Oliver, R.; Buehler, R.; Lee, J.; Crawford, T.; Kim, J. Impacts of Point of Interest (POI) Data Selection on 15-Minute City (15-MC) Accessibility Scores and Inequality Assessments. *Transp. Res. Part A Policy Pract.* **2025**, *195*, 104429. [\[CrossRef\]](#)
- Schönfelder, S.; Axhausen, K.W. Activity Spaces: Measures of Social Exclusion? *Transp. Policy* **2003**, *10*, 273–286. [\[CrossRef\]](#)
- Patterson, Z.; Farber, S. Potential Path Areas and Activity Spaces in Application: A Review. *Transp. Rev.* **2015**, *35*, 679–700. [\[CrossRef\]](#)
- Kwan, M.-P. The Uncertain Geographic Context Problem. *Ann. Assoc. Am. Geogr.* **2012**, *102*, 958–968. [\[CrossRef\]](#)
- Kwan, M.-P. Beyond Space (As We Knew It): Toward Temporally Integrated Geographies of Segregation, Health, and Accessibility: Space–Time Integration in Geography and GIScience. *Ann. Assoc. Am. Geogr.* **2013**, *103*, 1078–1086. [\[CrossRef\]](#)
- Abbiasov, T.; Heine, C.; Sabouri, S.; Salazar-Miranda, A.; Santi, P.; Glaeser, E.; Ratti, C. The 15-Minute City Quantified Using Human Mobility Data. *Nat. Hum. Behav.* **2024**, *8*, 445–455. [\[CrossRef\]](#) [\[PubMed\]](#)
- Zhang, S.; Hu, Z.; Zhen, F.; Kong, Y.; Tong, Z. Assessing the (in)Equality of an x-Minute City Accounting for Human Mobility Patterns. *Transp. Res. Part A Policy Pract.* **2025**, *192*, 104354. [\[CrossRef\]](#)
- Maciejewska, M.; Cubells, J.; Marquet, O. When Proximity Is Not Enough. A Sociodemographic Analysis of 15-Minute City Lifestyles. *J. Urban Mobil.* **2025**, *7*, 100119. [\[CrossRef\]](#)
- Graells-Garrido, E.; Serra-Burriel, F.; Rowe, F.; Cucchiatti, F.M.; Reyes, P. A City of Cities: Measuring How 15-Minutes Urban Accessibility Shapes Human Mobility in Barcelona. *PLoS ONE* **2021**, *16*, e0250080. [\[CrossRef\]](#) [\[PubMed\]](#)

23. Yang, M.; Qian, Y.; Li, X.; Ou, Y.; Zeng, J. River Valley Urban Network and Morphology: A Study on the Urban Morphology Evolution of Lanzhou. *PLoS ONE* **2024**, *19*, e0302686. [CrossRef] [PubMed]
24. Chen, Y.; Zhang, Z.; Lang, L.; Long, Z.; Wang, N.; Chen, X.; Wang, B.; Li, Y. Measuring the Spatial Match between Service Facilities and Population Distribution: Case of Lanzhou. *Land* **2023**, *12*, 1549. [CrossRef]
25. China Gansu Network. Planning Research and Guidelines for Supporting Facilities in Lanzhou's Fifteen-Minute Life Circles Released. 29 May 2020. Available online: <https://gansu.gscn.com.cn/system/2020/05/29/012394748.shtml> (accessed on 19 July 2026). (In Chinese)
26. Lanzhou Municipal Natural Resources Bureau; Lanzhou Urban and Rural Planning and Design Institute. *Planning Guidelines for Supporting Facilities in Lanzhou's Fifteen-Minute Life Circles (Draft for Review)*; Lanzhou Municipal Natural Resources Bureau: Lanzhou, China, 2019. (In Chinese)
27. Lanzhou Municipal Natural Resources Bureau; Lanzhou Urban and Rural Planning and Design Institute. *Research Report on Supporting Facilities for Lanzhou's Fifteen-Minute Life Circles (Draft for Review)*; Lanzhou Municipal Natural Resources Bureau: Lanzhou, China, 2019. (In Chinese)
28. Handy, S.L.; Niemeier, D.A. Measuring Accessibility: An Exploration of Issues and Alternatives. *Environ. Plan. A* **1997**, *29*, 1175–1194. [CrossRef]
29. Li, H.; Xiao, Y. From Rent Gap to Network Rent Gap: Metro Network Spillovers and Gentrification in Shanghai. *Popul. Space Place* **2026**, *32*, e70260. [CrossRef]
30. Hägerstrand, T. What About People in Regional Science? *Pap. Reg. Sci.* **1970**, *24*, 7–24. [CrossRef]
31. Chai, Y.; Li, C.; Zhang, Y. A New Time-Geography Research Framework of Community Life Circle. *Prog. Geogr.* **2020**, *39*, 1961–1971. [CrossRef]
32. Xiao, Y.; Zhang, Y. Displacement in Activities Space? Identification of Activity-Space-Based Gentrification via Mobile Phone Data. *Popul. Space Place* **2025**, *31*, e70026. [CrossRef]
33. Xiao, Y.; Li, X. Measuring Retail Gentrification with Large Language Models: A City-Scale Analysis of Shanghai Shopping Malls. *Appl. Spat. Anal. Policy* **2026**, *19*, 37. [CrossRef]
34. Wang, Z.; Xiao, Y. Rethinking Development and Regeneration in Urban and Rural China. *Trans. Plan. Urban Res.* **2026**, *5*, 3–15. [CrossRef]
35. Xiao, Y.; Cen, L.; Li, H. Green Equity or Green Gentrification? State-Led Urban Park Development in Shanghai, 2000–2020. *Urban For. Urban Green.* **2026**, *116*, 129225. [CrossRef]
36. Chang, F.; Wang, L.; Ma, Y.; Yan, C.; Liu, H. Do Urban Public Service Facilities Match Population Demand? Assessment Based on Community Life Circle. *Prog. Geogr.* **2021**, *40*, 607–619. [CrossRef]
37. Lanzhou Municipal People's Government. *Measures for the Planning, Construction and Management of Public-Service Facilities in Development Projects in Lanzhou Central Urban Area*; Lanzhengfa [2024] No. 29; Lanzhou Municipal People's Government: Lanzhou, China, 2024. (In Chinese)
38. Ratti, C.; Frenchman, D.; Pulselli, R.M.; Williams, S. Mobile Landscapes: Using Location Data from Cell Phones for Urban Analysis. *Environ. Plan. B Plan. Des.* **2006**, *33*, 727–748. [CrossRef]
39. De Montjoye, Y.-A.; Hidalgo, C.A.; Verleysen, M.; Blondel, V.D. Unique in the Crowd: The Privacy Bounds of Human Mobility. *Sci. Rep.* **2013**, *3*, 1376. [CrossRef] [PubMed]
40. Yuan, J.; Zheng, Y.; Xie, X. Discovering Regions of Different Functions in a City Using Human Mobility and POIs. In *Proceedings of the 18th ACM SIGKDD International Conference on Knowledge Discovery and Data Mining*; ACM: Beijing China, 2012; pp. 186–194.
41. Calabrese, F.; Ferrari, L.; Blondel, V.D. Urban Sensing Using Mobile Phone Network Data: A Survey of Research. *ACM Comput. Surv.* **2015**, *47*, 1–20. [CrossRef]
42. Diao, M.; Zhu, Y.; Ferreira, J.; Ratti, C. Inferring Individual Daily Activities from Mobile Phone Traces: A Boston Example. *Environ. Plan. B Plan. Des.* **2016**, *43*, 920–940. [CrossRef]
43. Chen, C.; Ma, J.; Susilo, Y.; Liu, Y.; Wang, M. The Promises of Big Data and Small Data for Travel Behavior (Aka Human Mobility) Analysis. *Transp. Res. Part C Emerg. Technol.* **2016**, *68*, 285–299. [CrossRef] [PubMed]
44. Järv, O.; Ahas, R.; Witlox, F. Understanding Monthly Variability in Human Activity Spaces: A Twelve-Month Study Using Mobile Phone Call Detail Records. *Transp. Res. Part C Emerg. Technol.* **2014**, *38*, 122–135. [CrossRef]
45. Widhalm, P.; Yang, Y.; Ulm, M.; Athavale, S.; González, M.C. Discovering Urban Activity Patterns in Cell Phone Data. *Transportation* **2015**, *42*, 597–623. [CrossRef]
46. Louail, T.; Lenormand, M.; Cantu Ros, O.G.; Picornell, M.; Herranz, R.; Frias-Martinez, E.; Ramasco, J.J.; Barthelemy, M. From Mobile Phone Data to the Spatial Structure of Cities. *Sci. Rep.* **2014**, *4*, 5276. [CrossRef] [PubMed]
47. González, M.C.; Hidalgo, C.A.; Barabási, A.-L. Understanding Individual Human Mobility Patterns. *Nature* **2008**, *453*, 779–782. [CrossRef] [PubMed]

48. Isaacman, S.; Becker, R.; Cáceres, R.; Kobourov, S.; Martonosi, M.; Rowland, J.; Varshavsky, A. Identifying Important Places in People's Lives from Cellular Network Data. In *Pervasive Computing*; Lyons, K., Hightower, J., Huang, E.M., Eds.; Lecture Notes in Computer Science; Springer: Berlin/Heidelberg, Germany, 2011; Volume 6696, pp. 133–151.
49. Lefever, D.W. Measuring Geographic Concentration by Means of the Standard Deviation Ellipse. *Am. J. Sociol.* **1926**, *32*, 88–94. [[CrossRef](#)] [[PubMed](#)]
50. Shannon, C.E. A Mathematical Theory of Communication. *Bell Syst. Tech. J.* **1948**, *27*, 379–423. [[CrossRef](#)]
51. Wilcoxon, F. Individual Comparisons by Ranking Methods. *Biom. Bull.* **1945**, *1*, 80. [[CrossRef](#)]
52. Kruskal, W.H.; Wallis, W.A. Use of Ranks in One-Criterion Variance Analysis. *J. Am. Stat. Assoc.* **1952**, *47*, 583–621. [[CrossRef](#)]
53. MacKinnon, J.G.; White, H. Some Heteroskedasticity-Consistent Covariance Matrix Estimators with Improved Finite Sample Properties. *J. Econom.* **1985**, *29*, 305–325. [[CrossRef](#)]
54. Breusch, T.S.; Pagan, A.R. A Simple Test for Heteroscedasticity and Random Coefficient Variation. *Econometrica* **1979**, *47*, 1287. [[CrossRef](#)]
55. Papke, L.E.; Wooldridge, J.M. Econometric Methods for Fractional Response Variables with an Application to 401(k) Plan Participation Rates. *J. Appl. Econ.* **1996**, *11*, 619–632. [[CrossRef](#)]
56. Luo, X.; Zhang, W.; Chai, Y. Research on Threshold Effects of Built Environment Settings in 15-Minute Life-Circles. *Geogr. Res.* **2022**, *41*, 2155. [[CrossRef](#)]
57. Wesolowski, A.; Eagle, N.; Noor, A.M.; Snow, R.W.; Buckee, C.O. The Impact of Biases in Mobile Phone Ownership on Estimates of Human Mobility. *J. R. Soc. Interface* **2013**, *10*, 20120986. [[CrossRef](#)] [[PubMed](#)]
58. Zandbergen, P.A. Accuracy of iPhone Locations: A Comparison of Assisted GPS, WiFi and Cellular Positioning. *Trans. GIS* **2009**, *13*, 5–25. [[CrossRef](#)]
59. Openshaw, S. *The Modifiable Areal Unit Problem*; Concepts and Techniques in Modern Geography, No. 38; Geo Books: Norwich, UK, 1983.
60. Sherman, J.E.; Spencer, J.; Preisser, J.S.; Gesler, W.M.; Arcury, T.A. A Suite of Methods for Representing Activity Space in a Healthcare Accessibility Study. *Int. J. Health Geogr.* **2005**, *4*, 24. [[CrossRef](#)] [[PubMed](#)]
61. Fotheringham, A.S.; Wong, D.W.S. The Modifiable Areal Unit Problem in Multivariate Statistical Analysis. *Environ. Plan. A* **1991**, *23*, 1025–1044. [[CrossRef](#)]

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