

Research on Measurement Methods for Spatial Accessibility and Service Areas of Public Libraries: Postprint

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Abstract

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Full Text

Research on Public Library Spatial Accessibility and Service Area Measurement Methods

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Abstract

[Purpose/Significance] Distance is a crucial factor influencing users' visits to public libraries. Public library accessibility serves as a metric for evaluating the rationality, scientific validity, universal coverage, and equalization of a city's public library layout. **[Method/Process]** Grounded in accessibility theory, this study explores various methods for delineating public library service areas and clarifies spatial accessibility concepts and indicators. Using ArcGIS and taking Suzhou Industrial Park as a case study, we empirically measured the spatial accessibility and service areas of the public library main-branch network, evaluating both straight-line and actual path distances, Thiessen polygon-delineated service areas, and public service guarantee circles. **[Result/Conclusion]** The measurement results provide strategic references for the refined layout of public library main-branch networks in urban spaces. The study proposes that the spatial layout of public library main-branch networks should integrate volume and coverage methods comprehensively, incorporate population factors in geographic space, and continuously optimize network layout according to the geographic sensitivity of different regions.

Keywords: public library main-branch system; public library network; spatial accessibility; service area; service radius

Public libraries play a vital role in social education, cultural services, and bridging the information gap. By providing public goods and spatial services, the universal and equalized public library main-branch system extends the mission and functions of public libraries to grassroots, community, and township levels, delivering information resources and public spaces. Providing universal and equal public services constitutes an important component of creating social equality and safeguarding fair rights, contributing to social capital development and improving social inclusion [1-2]. Achieving universal and equalized services through public library main-branch systems requires scientific planning and layout of branches based on population and demand. Administrative region-based layouts may lead to waste (such as establishing a branch in every community) or service blind spots (such as at the junction of administrative districts where each side expects the other to establish a library), thus creating conflicts with the existing institutional framework [3].

The scientific layout of main-branch systems not only affects the refinement of resource allocation and service delivery but also influences utilization rates and satisfaction levels, thereby impacting overall effectiveness. Meanwhile, the accessibility and convenience of public library geographic space can serve as measures of a city's public library layout rationality, scientific validity, universal coverage, and equalization. Distance represents one of the most common variables for measuring accessibility of public products including public libraries [4]. Relevant standards and practices primarily use distance as the basis for planning public libraries. The IFLA's *Public Library Standards* (2nd edition),

based on American residents' driving habits, specifies that public library service radius should be defined such that urban residents can reach a library within 15 minutes by car, and rural residents within 30 minutes [6]. The UK' s *Public Library Layout Standards* stipulate that in inner London, 100% of households should be within 1 mile of the nearest fixed library, while in outer London, 99% of households should be within 1 mile [7]. The IFLA/UNESCO *Guidelines for Public Library Service Development* require that in urban and suburban areas, travel time to the nearest library by private transportation should not exceed 15 minutes [8]. China' s relevant standards primarily specify service radii for libraries of different scales and types based on time spent cycling or taking public transportation [9]. Existing research has targeted public library service systems under "full coverage" objectives, constructing network placement models to explore effective new site establishment for regional "full coverage" [10].

However, in current public library layouts, further accurate calculation is needed to determine the service scope covered by each node, to identify service targets precisely, and to provide resources and services accordingly. Based on accessibility theory, this study delineates and clarifies the service areas of individual nodes within public library main-branch systems through distance measurement, identifying coverage blind spots in urban main-branch networks. Defining library coverage based on travel distance or time offers good operability for further planning of new sites under full coverage objectives. Compared with administrative region-based coverage, accessibility measurement' s significance lies in genuinely considering the possibility of users accessing library services, truly defining "full coverage" from a service perspective [10]. Using GIS analytical tools, this study compares and selects calculation methods for accessibility in specific geographic regions, applies both simple distance and complex path approaches to examine spatial variability in main-branch distribution within urban geography, and proposes strategies for refined public library layout based on accessibility. This offers reference value for improving layout scientificity, achieving precise services, and promoting high-quality development in public libraries. Particularly as public library main-branch layouts continue optimizing, this research can guide rational urban library layout, continuously enhance accessibility and service effectiveness, and improve convenience and user experience for target populations.

2 Spatial Definition of Public Library Accessibility

Accessibility research can be traced back to the late 1950s, when scholar W.G. Hansen defined accessibility as the potential for spatial interaction and the ability to overcome spatial separation [11]. Individual behavior-based accessibility typically refers to the convenience of traveling from one place to another, including distance and connection patterns between origins and destinations, as well as the value or quantity of alternative destinations [12]. In public library main-branch networks, measuring accessibility requires evaluating both the distance between users and their nearest branch and examining the spatial distribution

of accessible nodes throughout the entire network. Naturally, users rarely visit every node in the public library main-branch network but instead make choices within acceptable intervals and costs.

This implies that a “suitable” degree exists between users and library services, with this interval (distance from origin to destination) containing multiple meanings: availability, accessibility, accommodation, affordability, and acceptability [13]. **Availability** concerns supply and guarantee issues—whether public library establishment, collection allocation, and service provision are adequate to meet user needs. For instance, the number, area, hardware, staff, resources, and services of public library main-branches in a specific region are all factors currently specified in many regional public cultural service system policies. From a distribution and coverage perspective, accessibility refers to the relationship between library locations and user locations, evaluating the time and cost users spend reaching libraries and receiving services. **Accommodation** refers to the relationship between resource/service allocation and user acceptance, including operating hours and various service items (borrowing, reservations, etc.), as well as users’ awareness and actual satisfaction with provided resources and services. **Affordability** primarily concerns whether local fiscal revenue, public expenditure, and actual demand can support library site selection, construction investment, and operational costs. Public library value mainly manifests as social benefit, with regional and user-perceived value from library services also significantly impacting affordability. **Acceptability** refers to the relationship between regional user characteristics and library-provided resources and services, where user feedback on library resources and services affects local resource/service configuration. Libraries must consider user characteristics, demand patterns, and behavioral habits in their layout areas to optimize configuration and balance social inclusion, equal access, and specialized services. In short, availability refers to the number of local service points users can choose from; accessibility refers to distance friction between user locations and library sites (distance friction is a concept in urban geography—movement cost increases with distance, representing a measure of distance’s hindering effect in interactions). Both are concrete manifestations in spatial layout, and these two spatial dimensions are often combined as spatial accessibility [14].

Public library utilization is closely related to spatial accessibility. According to a 2002 U.S. survey, library usage rates were 52% among households within 1 mile of a public library, 50% for those 1-2 miles away, 47% for 3-5 miles, 41% for 6-10 miles, and only 34% for those over 10 miles away [15].

3 Methods for Measuring Spatial Accessibility and Service Areas

3.1 Volume Method and Coverage Method

Accessibility calculations typically employ two main approaches: volume and coverage methods. The volume method suits macro-level understanding of pub-

lic service supply and allocation, usually calculating the ratio between supply and population in specific regions—in essence, counting facility numbers in designated areas. The coverage method calculates distances from origins to given facilities, typically measuring the minimum distance between an origin and its nearest facility, the average distance to all facilities (movement cost), or summing all facilities (weighted by size) divided by distance friction effects to derive a distance index [16]. For public library main-branch systems, the volume method calculates the number of libraries in specific regions or areas, enabling comparison of accessibility levels across different regions or populations. The coverage method considers main-branch nodes as destinations within specific regions, examining the distance and time for target groups to reach these destinations [17].

China's 2008 *Public Library Construction Land Indicators* (hereinafter “Land Indicators”) and *Public Library Construction Standards* (hereinafter “Construction Standards”) classify public libraries into large, medium, and small scales based on service population: large libraries serve over 1.5 million; medium libraries serve 200,000-1.5 million; small libraries serve under 200,000 [18]. This primarily uses the volume method for library establishment. The Land Indicators' Article 18 proposes quantity indicators based on service population—for instance, when serving 1.5 million people, besides establishing a corresponding large library, one medium library per 500,000 population and one small library per 200,000 population are required [18]. The Construction Standards clarify quantity indicators that urban construction should gradually achieve [18].

The Land Indicators also employ coverage methods by specifying service radius requirements. Public library service radius refers to the maximum straight-line distance from users within the service area to the library. Users within this range can typically access and use the library conveniently, representing effectively covered populations. Article 18 proposes service radius indicators: 9 km for large libraries, 6.5 km for medium libraries, and 2.5 km for small libraries. These calculations assume average public transportation speeds of 20-30 km/h and bicycle speeds of 8-12 km/h. Large libraries' 9 km radius corresponds to approximately 60 minutes of cycling or public transit; medium libraries' 6.5 km radius corresponds to about 30 minutes; small libraries' 2.5 km radius corresponds to 20 minutes [18]. The provision that “no medium library should be established within a large library's 6.5 km service radius; no small library should be established within a medium or large library's 2.5 km service radius” [18] avoids clustering and duplication in urban public library construction, embodying universal coverage and equalization principles.

The volume method assumes each main-branch node has a specific service area, suitable for situations where users are unlikely to cross regions to use libraries. However, in densely populated cities, users may choose among several libraries, including the nearest one. Surveys show that users of urban main-branch nodes may come from relatively distant communities, not just the nearest community. In such cases, the coverage method proves more effective. It addresses

volume measurement limitations by drawing potential buffers around origins—using each main-branch node as the center with specific service radii to delineate and extract each node’ s service area. In library and information science research, coverage rates are often based on library numbers per geographic unit or population density, with studies measuring that users’ farthest distance to local libraries ranges from 1.6 km to 3.2 km [19], using this to define library service areas [20].

3.2 Service Radius and Actual Path Distance

In main-branch accessibility research, different standards must be selected based on actual conditions for determining origins and measuring distances. Although studies show various methods’ results are closely correlated [24], different measurement methods have varying practical effects. Straight-line (Euclidean) distance suits larger geographic scales (national level) and offers simpler calculation, also appropriate in dense urban areas. Research indicates straight-line and network distances are typically highly correlated in cities [25], while road network methods better suit suburban and rural areas [24]. In smaller-scale micro-level studies, differences between straight-line and road network distances often reflect the former’ s inability to account for terrain features—actual paths may be restricted by physical barriers like rivers, lakes, mountains, and highways. For instance, Suzhou’ s water area accounts for 42.5% of its territory, including Taihu Lake, Yangcheng Lake, Jinji Lake, and Dushu Lake, plus 2.7% hilly terrain, making road network distance measurement more appropriate for reflecting accurate real-world results. Additionally, spatial equality must be fully considered in main-branch accessibility research.

3.3 Delineating Service Areas: Application of Thiessen Polygons

In delineating public library main-branch service areas, GIS Thiessen polygon tools can analyze library influence zones. Thiessen polygons, also known as Voronoi polygons, map public library geographic coordinates in ArcGIS to visualize locations and regions, then generate polygons to analyze each library node’ s influence zone—graphically representing service areas. The principle assumes that relative to all other points, the area is closest to a particular point; if a library user is located within “A’ s” Thiessen polygon, their nearest library is “A” [1].

In service area delineation, Thiessen polygons calculate each library’ s service scope under existing distribution, determining distance’ s impact on library visits. Defining service areas by distance is the primary issue in library layout planning and services. Libraries can use delineated service areas to access census data and other socioeconomic information, create user profiles, and design better resource allocation and customized services.

4 Empirical Measurement of Public Library Network Spatial Accessibility and Service Areas: A Suzhou Industrial Park Case Study

Geographic coordinates of Suzhou Industrial Park libraries, branches, and community reading rooms were imported into ArcGIS, with community coordinates presented similarly. Road network data was loaded to measure actual path distances.

4.1 Accessibility Measurement Case Study

Based on accessibility theory, straight-line distances from each community to all library nodes in the Industrial Park were calculated, with minimum values identified as the nearest library node—considered the access point for that community's residents. This yielded a list of each community's nearest library node by straight-line distance.

Using the same method, actual path distances from communities to the nearest library node were calculated based on the real road network, producing a list of nearest library nodes by actual path distance (see Table 1).

Table 1 Distance from Each Industrial Park Community to the Nearest Library

Measurement Method	Average Distance (m)	Standard Deviation	Max Distance (m)
Straight-line distance	1056.72	-	6443 (Yangchenghu Village Community to Qingyuan Community Branch)
Actual path distance	-	-	7124 (Yangchenghu Village Community to Science & Technology City Neighborhood Center Branch)

The data shows that the average distance from communities to the nearest library is approximately 1 km, but with large standard deviations, indicating significant variation. The farthest community is Yangchenghu Village Community, with a 6,443 m straight-line distance to its nearest Qingyuan Community Branch, and a 7,124 m actual path distance to its nearest library (Science &

Technology City Neighborhood Center Branch). Notably, the nearest library by straight-line distance differs from that by actual path distance. Actual path distances are generally longer than straight-line distances, largely related to urban road network layout—denser road networks make actual and straight-line distances more similar, while sparse networks create larger discrepancies. Among 129 communities, 70 have community reading rooms as their nearest node and 59 have library branches, demonstrating that community reading rooms play a significant role in shortening distances and improving convenience. The analysis reveals that actual path distance measurement is more precise, though necessarily more complex due to road network data requirements.

4.2 Service Circle Coverage

Following international standards of 1.6 km and 3.2 km, buffer zones were created around each library node, generating both straight-line and actual distance buffers (see Figure 1 [Figure 1: see original paper] and Figure 2 [Figure 2: see original paper]). Comparison shows that using these international standard buffer zones, the Industrial Park's main-branch system basically covers the entire area by straight-line distance, but actual path distance reveals uncovered areas when excluding lake surfaces, requiring further refined layout.

Similar to some Shenzhen districts, the Industrial Park also incorporates libraries into a “10-minute service circle,” though without specifying transportation mode or average speed. Therefore, time settings of 5, 10, and 20 minutes were used, with walking speed at 5 km/h and cycling speed at 10 km/h to create library node buffers (see Figure 3 [Figure 3: see original paper] and Figure 4 [Figure 4: see original paper]).

Based on actual path calculation, neither walking nor cycling covers the entire district, though cycling coverage approaches international standards (see Figure 4). To achieve full coverage, the main-branch layout requires further refinement for overall regional balance. Priority areas for layout must consider not only spatial coverage blind spots but also transportation habits and convenience for target populations.

4.3 Service Area Delineation

Thiessen polygons were generated for the Industrial Park public library network to estimate each node's service area (see Figure 5 [Figure 5: see original paper]). The figure shows that different library nodes cover unequal service areas. Central areas with dense library distribution have relatively small service zones, while peripheral areas with sparse distribution have larger zones requiring comprehensive consideration of additional nodes to break up large service areas. Central districts have dense populations, and adding nodes will dilute concentrated demand.

From a spatial accessibility perspective, ensuring all users can visit libraries nearby requires precise positioning of each node's service area to better under-

stand users' socioeconomic characteristics and provide customized, specialized resources and services, enhancing user experience and service effectiveness. Layout planning should continuously alleviate distance-related barriers, increase library attractiveness, enable convenient access for all users, and achieve true universal coverage and equalization.

Thiessen polygons delineate service areas from the perspective of the overall regional library network, essentially allocating service regions based on library nodes. The case study shows each node's service area varies without distinguishing between branches (secondary) and reading rooms (tertiary). For instance, in peripheral areas, Qingyuan Community Branch's service area is smaller than Putian Community Reading Room's, while in central areas, Jingcheng Branch's service area is smaller than Fengqingshui Community Reading Room's. However, construction standards and service capacities differ between branches and community reading rooms, as do actual coverage and ability to meet demand.

5 Strategies for Refined Spatial Layout of Public Library Main-Branch Networks in Urban Space

5.1 Selection of Volume and Coverage Methods

Accessibility is a crucial factor for optimizing public library main-branch spatial layout. From universal coverage and equalization perspectives, library node placement should follow proximity principles, considering each community's access convenience. As main-branch networks extend into communities, maximizing overall network benefits requires addressing which nodes need priority placement and how to position them—key issues in refined spatial layout.

The volume method facilitates measuring library density—representing user choice of access points—suitable for quantifying coverage levels in specific regions and determining libraries' service “bandwidth” for inter-regional network development comparison. The coverage method delineates areas most likely to access libraries based on distance, revealing whether main-branch nodes comprehensively cover the entire region and identifying service gaps for further layout. It can evaluate actual coverage proportions, improve layout quality, reveal distance factors affecting utilization rates, and assess whether layout achieves geographic equalization from a user perspective—suitable for precise service area determination in specific cities. Therefore, combining volume and coverage methods enables analysis of both quantity and quality in main-branch layout.

5.2 Population Considerations

Population is an essential factor in main-branch layout. China's Land Indicators and Construction Standards use service population as the basis for classifying library scales. Library node placement must consider which regional populations are primary service targets, their characteristics and needs, and resource

allocation methods. However, accurate target population numbers are difficult to obtain in practice; both actual and potential users constitute service targets. In public library assessments, user objects are defined as permanent residents, but urban population complexity makes precise community-level data difficult to obtain. Both library layout and resource/service refinement rely on user positioning and profiling, requiring further research.

Based on service area delineation, population-weighted average straight-line and actual path distance calculations can more accurately assess accessibility impacts. The formula for road network-weighted average distance is:

$$\Delta = \frac{\sum_{i=1}^n d_i p_i}{\sum_{i=1}^n p_i}$$

Where Δ represents the community road network-weighted average distance, d_i is the road network distance from community i to the nearest library, and p_i is the community population.

In Suzhou Industrial Park's main-branch system, branch and community reading room functions differ between high and low population density areas. In central dense areas, community reading rooms share branch service loads, diverting demand through specialized resources and services—users can conveniently access multiple nodes and choose based on specific needs. In peripheral sparse areas, reading rooms compensate for insufficient branch placement, meeting needs of users traveling longer distances. Research shows that users far from libraries tend to seek alternatives like internet access [1].

5.3 Geographic Sensitivity and Behavioral Patterns

Refined urban public library main-branch distribution must also consider varying spatial patterns across geographic scopes (urban center, community, construction sites), requiring sensitivity analysis at multiple urban geographic scales [27]. Road network density significantly affects actual travel distances to libraries. In city centers with developed road networks, straight-line and actual path distances are similar, while in peripheral or sparse areas, they diverge substantially—actual distance measurement should be used. Site selection planning should fully consider spatial patterns across different geographic scopes to continuously optimize library accessibility.

When conditions permit, actual path distance should be used to determine service scope, further reducing distance barriers. The case study's Figures 1-4 demonstrate that public service guarantee circles must consider target populations' travel modes and habits to achieve accessibility guarantees. Combined with questionnaire and field surveys, GIS can precisely identify user behavior patterns. For example, when library-user distances are large but users are willing to spend time visiting, perceived distance may be shorter than actual

distance. Combining actual and perceived distances can better improve user experience and service effectiveness [1].

Accessibility is key to library utilization and visitation. GIS-based accessibility measurement can visually express urban public library network layout effects, holding significant importance for optimizing distribution and improving visitation rates. To maximize urban public library network effectiveness, libraries should start from distance to precisely position each node' s service area, better understand specific nodes' user socioeconomic characteristics, and provide customized, specialized resources and services for different regional users, enhancing experience and effectiveness. Layout planning should continuously alleviate distance-related usage barriers, increase library attractiveness, enable convenient access for all users, and achieve true universal coverage and equalization.

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