ASSESSING PATH CHOOSING IN MOUNTAINOUS CITIES VIA PEDESTRIAN NETWORK DATA AND SUBWAY STATION OBSERVATIONS

A Case Study of Jiefangbei, Chongqing

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Abstract. In high-density mountainous cities, pedestrian system becomes more challenging due to terrain constraints, which amplifies the difficulty associated with walking. Consequently, many individuals opt "subway + walking" as their primary mode of travel, which is deemed more efficient. This research focuses on a case study in the Jiefangbei area of Chongqing, known for its intricate terrain and dense urban fabric, and assesses people's walking selection around subway stations within 10-minute walking isochrone. It employs space syntax with weighted topographical street network to establish an evaluation system. The evaluation system comprises three primary indicators: road accessibility, walking attractiveness and walking efficiency. It encompasses both the physical and perceptual factors influencing people's walking preferences in the walking system. This research utilizes python to crawl POI points, Arcgis and sDNA to process and visualize data and JS divergence for final similarity analysis. By conducting an in-depth assessment of the walking system around subway stations in mountainous urban areas, this paper attempts to provide strategies aimed at enhancing the walkability in mountainous cities.

Keywords. Walkability, Path choosing, Spatial Design Network Analysis, Pedestrian network, Mountainous city, Weighted Network Analysis

1. Introduction

Complex terrain shapes diverse urban pedestrian spaces in mountainous cities, while the natural landscapes contribute to the attractiveness of walking systems. Walking choices adapt to the 3D environment and integrates seamlessly with the surroundings.

The transportation network around subway stations is closely connected to pedestrian movement. Chiaradia (Zhang & Chiaradia, 2019) proposed that the density of station areas is significantly correlated with the volume of subway and walking

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traffic, and enhancing walkability in the vicinity of station areas is crucial for improving the travel quality of rail passengers.

Existing evaluations (Zhou & Long, 2017) of walkability primarily employ two approaches: objective assessments of the built environment and subjective evaluations of walking characteristics. Objective assessments of the built environment primarily evaluate the walk accessibility and walk connectivity from the perspective of urban network morphology. While subjective evaluations encompass assessments of perceived walking environments and walking path choices.

Various methods have been developed to evaluate walking environments, including indicators of walking environment quality (Van Dyck et al., 2013), Likert scale and PLPS survey methods (Gehl, 2013), etc. Additionally, Agrawal et al. (Weinstein Agrawal et al., 2008) found that travel distance and time were the primary factors for path choices based on a study of path selection patterns at five rail stations.

Current research on walkability mostly neglects the influence of terrain variations in mountainous cities. As a result, this study aims to provide a scientifical evaluation to analyse the relationship between mountainous road network and people's walking choices by software simulation and data analysis.

2. Methods

2.1. RESEARCH OBJECT

The study selects the central area Jiefangbei in Chongqing, China as the study case in Figure 1. Chongqing locates in the eastern part of the Sichuan Basin, characterized by parallel ridge-valley landforms, with dense concentrations of population, traffic, and buildings in this region. Jiefangbei situates in the Yuzhong district, and exhibits typical mountainous topography. The irregular transportation system reduces transport accessibility and unique mountainous characteristics result in scarce land for development. In 2019, the population density in this area reached 27,000 people per square kilometer, making it a typical high-density area in a mountainous city. Therefore, choosing Jiefangbei as the case holds value and practical significance.

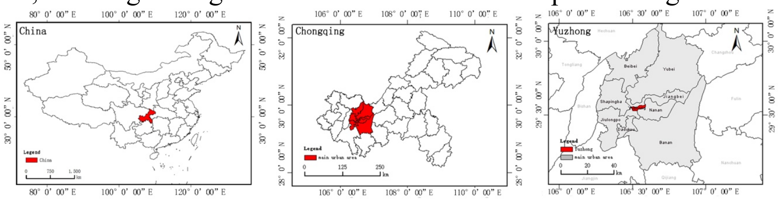

Figure 1 Study area

Studies have shown that the psychologically comfortable walking time for individuals is approximately 10 minutes (800m) (Zielstra & Hochmair, 2011). Thus, this study selects four subway stations as the starting points to construct an analysis area. Time impedance is used to divide the service area into five-minute (400m) and ten-minute (800m) isochrones shown in Figure 2. From left to right in the figure, the subway stations are Jiaochangkou, Linjiangmen, Xiaoshizi, and Chaotianmen.

The road network data used in this study is sourced from the OSM website (OpenStreetMap, n.d.), DEM elevation information for the roads is obtained from

Geospatial data cloud (Geospatial Data Map, n.d.) and Poi data points is extract by python.

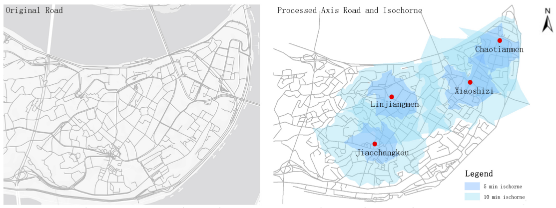

Figure 2 Pedestrian Network and Isochrone

2.2. TECHNICAL APPROACH

Normally, walkability refers to the extent to which supports the built environment or encourages walking (Southworth, 2005). Good walkability includes providing safe and comfortable pedestrian spaces, allowing pedestrians to reach various destinations within reasonable time and cost, or offering visual attractiveness along the way.

Different route choices attributes to various impacts on the overall efficiency and sensation of walking. Based on relevant studies in walkability, the evaluation primarily focuses on the organizational form and the spatial environment of pedestrian network. Therefore, in this study, the evaluation will be according to the built environmental and psychological factors. They both influence each other, and have an impact on the choice of walking paths.

The model ultimately forms a walking selection evaluation system consisting of a "criteria– primary indicator – secondary indicator " framework, and selects road accessibility, road attractiveness, and walk efficiency as primary indicators as Figure

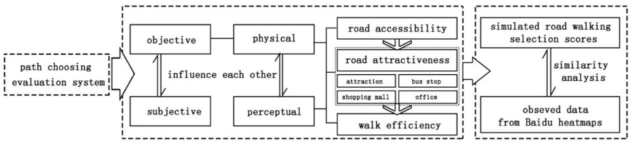

Figure 3 Research methods

3.

Then we made some adjustments to the weight of evaluation indicators according to expert opinions, statistical data, and their significance in mountainous cities. the indicators weights are listed in Table 1.

Road Accessibility	0．4198	Road Accessibility	0．4198
Road Attractiveness	0.3449	Bus stops	0.151
		Malls	0.264
		Offices	0.264
		Attractions	0.321
Walking Efficiency	0.2353	Time	0.2353

Table 1 Classification and Weight

The evaluation model is presented as follows:

$$I'_i = W_{ui} I_{ui} + W_{vi} I_{vi} + W_{ti} I_{ti} \; (i = 1, 2, 3, 4 \ldots\ldots m)$$

In the equation, I'_i represents the comprehensive score of road i. W_{ui}, W_{vi}, W_{ti} represent the weight value of the road accessibility, attractiveness and walking efficiency respectively. I_{ui}, I_{vi}, I_{ti} represent the normalized value of each at location i. m represents the number of bus stations.

While due to the intense elevation changes in mountainous cities, traditional evaluate methods always fail to comprehensively consider the influence of topography on pedestrian movement. Thus, this research incorporates variations in road gradient as a factor to assess the values of each indicator.

2.3. NORMALIZATION

Different evaluation indicators have varying dimension and units, which influence the results of analysis. To eliminate the dimensional impact between indicators and enable the comparability, data should be normalized to a range of [0, 1]. Then the normalized results are aggregated to obtain the final evaluation scores.

$$M = (N - Min_{Value})/(Max_{Value} - Min_{Value})$$

In the equation, N and M represent the original and the normalized values of the sample data. Max_{Value} and Min_{Value} refer to the maximum and minimum values within the sample data respectively.

3. Path Choosing Evaluation

3.1. VERTICAL ROAD ACCESSIBILITY

To facilitate quantitative research, we develop a spatial syntax analysis model to calculate the vertical road accessibility of the road network. The sDNA network analysis tool, developed by Cardiff University in the United Kingdom is utilized to analyse the road network on the Arcgis platform (Cooper & Chiaradia, 2020).

Based on the obtained road network with DEM data and the POI interest points, we construct a planar and a vertical road network map within the study area by Arcgis (Yin, 2017). The road network is further segmented at intersections to generate a 3D axial line network as depicted in Figure 4 below:

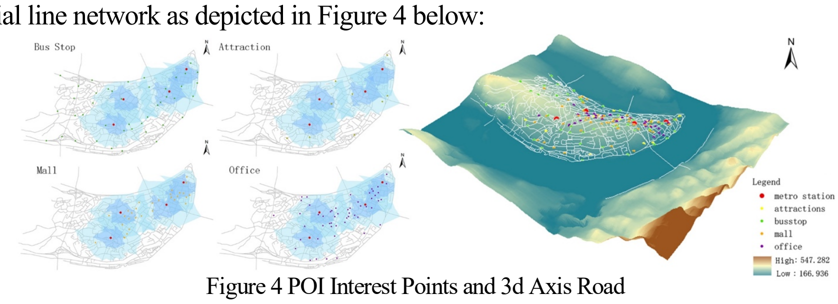

Figure 4 POI Interest Points and 3d Axis Road

NQPD（Network Quantity Penalized by Distance）can be considered as a measure of integration in spatial syntax research. It represents the relationship between a specific spatial unit and the overall or local spatial context. In this study, the NQPD was used as the accessibility indicator of the 3D transportation network in the Jiefangbei central urban area(Song et al., 2020). Where a higher value signifies better accessibility. The calculation formula is as follows:

$$NQPD(x) \ = \sum_{y \in R_x} \frac{p_y}{d(x,y)}$$

R_x represents the set of all other lines that line x reaches along a certain distance, p_y represents the proportion of line y to all other lines within the search radius, $d(x, y)$ represents the shortest path distance from point x to point y.

In the context of sDNA, the slope values for each road segment are computed and converted into impedance then preprocessed and analysed by the Euclidean_angular metric. The Euclidean_angular metric is employed to account for both the straight-line distance and directional difference between positions, which leads to a comprehensive assessment of connectivity between positions. The accessibility is depicted in the Figure 5, the data is normalized to ensure the additivity finally.

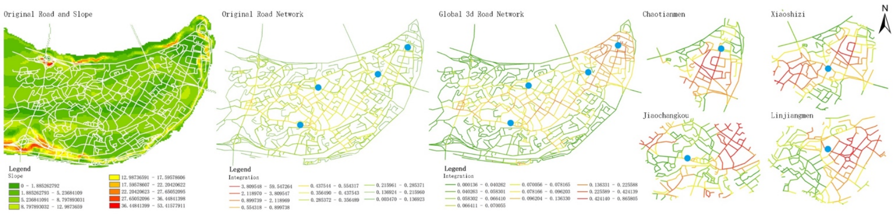

Figure 5 Road Accessibility

Based on the results, it is evident that the areas without considering terrain factors shows the highest pedestrian accessibility in the central region where the road network is most dense. Then it gradually decreases towards the outer areas as the density of the road network reduce. When terrain factors are taken into account, the areas with higher accessibility show noticeable deviations. Central zone is affected by the influence of slopes and central red-coloured area contracts towards the inner region.

3.2. WALKING EFFICIENCY

The average walking speed of a healthy adult ranging from 1.1 to 1.5 m/s. Young

No.	Slope (i)	Slope (∠)	Type	Walking speed
1	0≤i≤0.06	0°≤∠≤3°	Flat slope	1.4m/s
2	0.06＜i≤0.15	3°＜∠≤9°	Gently sloping ground	1.2m/s
3	0.15＜i≤0.3	9°＜∠≤17°	Medium slope land	1.1m/s
4	0.3＜i≤0.4	17°＜∠≤22°	Steep ground	1.0m/s
5	0.4＜i≤0.5	22°＜∠≤27°	Steep slope	0.8m/s
6	0.3＜i≤0.5	27°＜∠≤31°	escarpment	0.6m/s
7	i＞0.6	∠＞31°		

groups is typically around 1.48 to 1.51 m/s, while elders tend to have a slightly slower walking speed of around 1.25 to 1.32 m/s [(Manual, 2000). Above all, the average walking speed for a person on flat terrain is approximately 1.4 m/s.

Table 2 Gradient classification and walking speed setting of uphill sections

In mountainous areas, the variation in terrain elevation affects walking speed. Research indicates that when the slope exceeds 3%, for every 10% increase in slope, pedestrian speed decreases by 0.1 m/s. Therefore, the speed required for different walking segments can be calculated as Table 2, representing the walking efficiency based on the time it takes to traverse the segment.

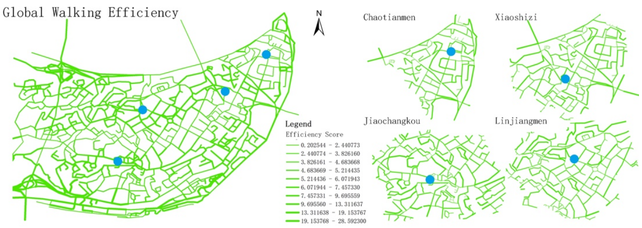

Figure 6 Walking Efficiency

As shown in the Figure 6, the effective data is divided into 10 categories by Jenks method. The width of the lines indicates the magnitude of the corresponding values.

According to the calculations, the walking efficiency exhibits lower efficiency in the central region then gradually increases from the center towards the edges. The several tens of meters steep slopes leading from the center to the sides has a significant impact on pedestrians' walking efficiency.

3.3. ROAD ATTRACTIVENESS

The service facilities walkability is vital in reflecting the residents' quality of life and the pedestrian-friendly environment. Diverse service facilities could enhance the attractiveness of travel. Therefore, evaluating the density distribution of service facility is beneficial for quantitatively assessing walkability (Wang & Yin, n.d.).

Kernel density analysis calculates the density distribution of features within a neighbourhood. By estimating the density of points or lines falling within each cell, it enables the visualization of clustering characteristics at different spatial scales.

$$f_h(x) = \frac{1}{nh}\sum_{i=1}^{n} k\left(\frac{x - x_i}{h}\right)$$

k represents kernel function, n represent number of line features, $(x - x_i)$ represents the distance from each individual unit feature in the sample to the central feature, h represents search radius.

In this study, we employed the kernel density to assess the four types of service facilities—tourist attractions, bus stops, office buildings, and shopping malls in Figure 7, which have high correlations with pedestrian attractiveness in the relevant research

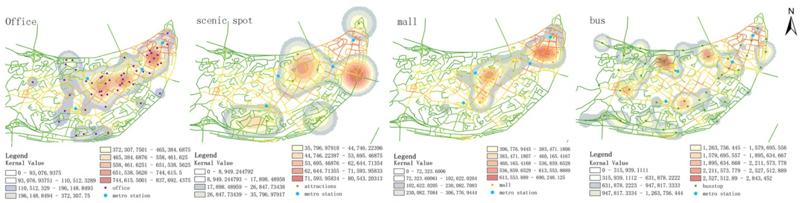

Figure 7 Kernel Density Estimation of POI Points

context. Considering the walking distance decay coefficient, we investigated the influence of facility density on pedestrian attraction.

Generally, peoples' travel willingness diminishes as the distance to their destination increases. A commonly used approach is to employ piecewise function for distance

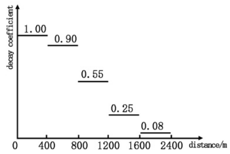

Figure 8 Walking Distance Decay Coefficient

attenuation rule calculating, as shown in Figure 8.

Combining the distance attenuation function, a comprehensive indicator of pedestrian attractiveness within the area can be derived in Figure 9. Since the study primarily focuses on the range of 0-800 meters (a ten-minute walking radius), the attenuation coefficient for distance falls between 1 and 0.9. The formula is as follows:

$$W = \sum_{i}^{n} (W_i \times D_i)$$

W represents the walking attractiveness index corresponding to each point. W_i represents the weight value assigned to a specific facility. i denotes different facilities. D_i represents the attenuation coefficient at i.

Taking into account the terrain conditions, the weights assigned to road transportation, shopping malls, office buildings, and tourist attractions are 0.151, 0.264, 0.125, and 0.321, respectively.

Figure 9 Walking Attractiveness

3.4. FINAL SCORES

Normalize all the data and calculate the final path scores based on the evaluation model.

According to the overall results in the Jiefangbei central area, a multi-core spatial clustering pattern can be observed in Figure 10 with a gradual decrease from the center

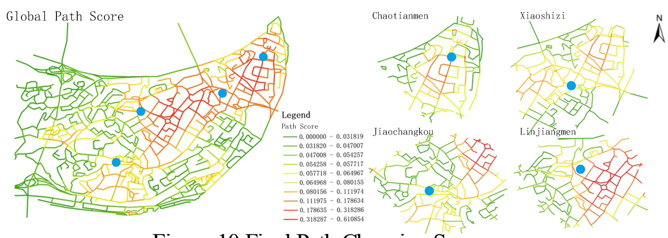

Figure 10 Final Path Choosing Scores

towards the edges and from east to west. The areas with high pedestrian scores are primarily concentrated in the central pedestrian street and around Chaotianmen wharf, and tourist attractions along the mountainside like Shibati.

From the perspective of ten-minute isochrones, the pedestrian score results around stations exhibit strong clustering characteristics. The result shows one-sided or two-sided distributions particularly in areas adjacent to main roads and high-density facilities. The scores sharply decrease in other directions, which indicates poor transitions and inefficient spatial connections between different rail transit stations.

4. Results Verification

With the popularization of big data applications in the urban planning, LBS data have been widely used in urban research in recent years(Rao & Li, 2019). By mining and analysing location-based big data, real-time and objective perspectives can be provided for analysis in transportation planning, it is helpful in addressing issues such as timeliness and dynamics that are lacking in traditional researches.

Baidu Maps' heat maps are based on LBS data of mobile phone users' geographic locations. The maps depict the population count within a specific spatial range at a particular moment. They use different color blocks overlaying on a web-based map to visually describe the distribution of people in the city in real-time (Wu & Ye, 2016).

We crawled the 15th and 16th levels heat maps for different time intervals on November 9, 2023 as describes in Figure 11. The heat map color was used as an indicator for population data to verify the correlation with the evaluation model result.

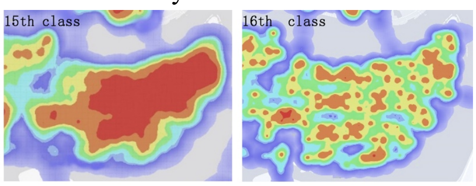

Figure 11 Baidu Heatmap 15th and 16th Class

Studies found that the Alpha channel values of Baidu heat maps range from 60 to 194, different colors have continuous intervals, this study follows the relevant research to extract the population count from the Baidu heat maps and reclassify them into seven levels based on their color intensity, from low to high. Results are listed in Table 3.

Color	Blue	Light blue	Cyan	Green	Yellow	Orange	Red
Density	——	——	≤10	＞10-20	＞20-40	＞40-60	＞60
Alpha	60-132	＞132-138	＞138-151	＞151-163	＞163-170	＞170-179	＞179-194
Score	1	2	3	4	5	6	7

Table 3 Correspondence between population aggregation and Alpha channel value

JS divergence is a metric used to measure the similarity between two probability distributions, based on the principle of entropy optimization. Generally, JS divergence values range from 0 to 1, as the value approaches 0, it indicates a higher similarity between the distributions, whereas a value closer to 1 indicates greater dissimilarity(Menéndez et al., 1997).

In this study, JS divergence analysis will be conducted on empirical data and simulated data to understand the similarity between the two distributions. The formula for JS divergence is as follows:

$$JSD(P||Q) = \frac{1}{2}\sum p(x)\, log\frac{p(x)}{\frac{p(x)+q(x)}{2}} + \frac{1}{2}\sum q(x)\, log\frac{p(x)}{\frac{p(x)+q(x)}{2}} + log2$$

P and Q represent empirical data and simulated data, respectively.

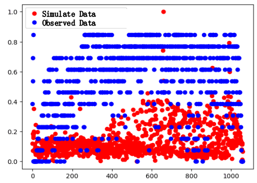

Figure 12 JS divergence result

The simulated data and observed data were normalized by excel. JS divergence analysis was carried out by python. Figure 12 illustrates the distribution patterns between the two datasets. The result yields a JS divergence value of 0.1146, which is close to 0. Therefore, it can be concluded that the simulated walkability and the actual pedestrian flow demonstrate a relatively similarity.

5. Conclusion

Based on walk score and walkability, this paper develops an assessment model for pedestrian path selection in mountainous urban conditions, using the central urban area of Jiefangbei in Chongqing as a case study. By considering slope variations, walking efficiency, and attractiveness, the model enhances the accuracy and visual representation of path evaluation.

The results indicate that people's route choices exhibit clustering behavior and spatial discontinuity in mountainous cities. The constraints lead to fragmented distributions of crowded areas with saturated facilities and congestion, while other areas remain neglected and lack vitality. It affects the walking experience of individuals, presenting challenges for the elderly and disabled.

Pedestrian system plays a vital role in mountainous urban environments. It is crucial to improve spatial utilization and interactions between people and the environment. It creates a diversified, user-friendly, and sustainable walking system for all groups of people in mountainous pedestrian environments.

5.1. LIMITATION AND EXPECTATION

The current stage of this research has limitations due to data sources, analytical capabilities, and insufficient theoretical and practical experience. To improve the accuracy of walking choice scores, it is necessary to evaluate street environmental factors such as green vision rate and sky visibility rate. Additionally, using more precise LBS data can address the deficiency in actual pedestrian flow data and improve the fitting of actual and simulated similarities. Gathering a comprehensive range of service facilities would yield more accurate results.

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