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Evaluating the Quality of Children's Active School Travel Spaces and the Mechanisms of School District Friendliness Impact Based on Multi-Source Big Data

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Abstract: With the advancement of child-friendly urban planning initiatives, the significance of Active School Travel Spaces (ASTSs) in shaping urban development and promoting the physical and mental well-being of children has become increasingly apparent. This research focuses on 151 public primary schools in the central urban area of Lanzhou City. Utilizing the Amap pedestrian route planning API, we establish a walking route network, evaluate the paths using spatial syntax and street view recognition methods, and analyze their influencing factors using a Geographic Detector model. The results show the following: ① The overall friendliness of ASTSs in Lanzhou City is moderate, with 44% of school districts exhibiting low friendliness. ② The distribution of child friendliness in ASTS exhibits a "core-periphery" pattern. Anning District demonstrates higher friendliness compared to Chengguan District and Qilihe District, while Xigu District exhibits the lowest level of friendliness. ③ Different levels of friendliness have different tendencies for access, safety, and comfort. A high degree of friendliness favors comfort. Low friendliness has the lowest requirements for safety and comfort. ④ Population density and transportation convenience exert a significant positive impact on friendliness, while the size of the school district and the centrality of schools have a negative impact. The synergistic effects among these influencing factors notably enhance the explanatory power of friendliness.

Keywords: active school travel; child friendly; influencing factors; streetscape identification; spatial syntax; Lanzhou city

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1. Introduction

In 1996, the United Nations International Children's Emergency Fund (UNICEF) and the Human Settlements Programme launched the child-friendly city (CFC) initiative. The objective was to advocate for governments to realize children's rights, support children in their healthy growth, and ensure their overall well-being [1]. V. Vinueza succinctly summarized the core objective of promoting child-friendly cities as "children being able to walk safely on the streets and meet and play with friends freely" [2]. This urban development concept has been recognized and has had certain effects in many countries, benefiting over 380,000 children in more than 30 countries [3]. However, this urban development concept has not been given much attention in China. Since the early 20th century, rapid urbanization and population growth in China have led to the predominant mode of transportation within cities being motor vehicles, with a decreasing proportion of pedestrian travel on streets [4]. More and more street designs prioritize road traffic and parking spaces, weakening the rights of pedestrians on the streets. As important users of street walking, children are rarely considered for independent pedestrian-friendly designs in street planning [5].

Active school travel (AST) refers to children traveling to and from school without the use of motorized vehicles. Due to their young age, walking remains their primary means of travel [6]. AST is vital for fostering Children's Independent Mobility (CIM). Research on

AST holds significant importance, not only for enhancing children's physical and mental health but also for the development of child-friendly cities [7]. Current research on AST mainly focuses on three aspects. Firstly, the selection of walking routes to and from school involves researchers examining children's perceptions of the current environment, such as the safety and comfort of the routes, to propose optimized travel routes [8]. Secondly, the measurement of the quality of commuting spaces investigates children's behaviors in different types of spaces after school [9]. Thirdly, the factors influencing AST are studied. On one hand, analyzing children's motivations, preferences, and barriers to choosing walking or cycling sheds light on the psychological and social mechanisms behind their choices [10,11]. On the other hand, researchers have explored the connection between road feasibility, streetscape characteristics, and children's perceptions of walking to and from school [12,13]. Currently, there is limited research considering the overall quality of commuting spaces based on AST routes, and past studies often separate the spatial quality of commuting paths from the influencing factors of child-friendly spaces. This results in few studies considering the driving forces of child-friendly spaces from a holistic perspective.

Therefore, this study focuses on the commuting paths of public primary schools in the central urban area of Lanzhou City. The commuting paths are constructed using the Amap pedestrian route planning API, and specific indicators of friendliness are quantified by combining spatial syntax and street view recognition methods. The entropy method is used, along with adjusted indicator weights, to comprehensively determine the level of friendliness. Finally, geographic detectors are employed to identify the influencing factors of this friendliness. Theoretically, this study enriches the measurement system of spatial characteristics of children's commuting paths and empirically validates the factors influencing friendliness. In practice, it provides a reference for the planning, construction, and management of child-friendly cities in Lanzhou City, and offers a more scientific theoretical basis for advancing the development of child-friendly cities.

2. Literature Review

2.1. ASTS Definition

Active School Travel Space (ASTS) is an urban space closely related to AST behavior. Currently, there is no clear terminology for ASTS. According to the relevant literature, ASTS can be categorized into linear space and nodal space. Linear space forms the backbone of the entire pedestrian space system. Many countries have requirements for the linear space design of commuting paths. For instance, Japan, in the early 21st century, required the inclusion of commuting paths in the "National Road Mid-Term Planning Draft" to improve the quality of commuting paths while increasing their coverage rate. The United States outlined the design steps for commuting paths in the "Student Walking Safety Manual". Germany, through a series of activities ensuring the safety of commuting traffic, traffic education, and training measures, gradually encourages children to independently travel to school using environmentally friendly transportation [14]. Linear space refers to children's choice of the shortest walking distance between home and school, optimizing service access at reduced travel costs. Furthermore, due to children's physical stamina and commuting time constraints, they are likely to choose the shortest route in terms of travel time [15]. Some scholars have determined that school travel time remains a determining factor in route selection through traffic surveys [16]. In summary, this linear spatial configuration is inherent from the initial design phase and is shaped into a specific space by students actively commuting. These spaces objectively influence the friendliness of the school district. Nodal space mainly consists of the school gate space, important nodes on walking routes, and residential area nodes. Considering the accessibility and operability of research content and data, we define ASTS as the shortest route for children to walk to and from school and the nodal space of 200 m around the school gate.

2.2. ASTS Measurements

The measurement of ASTS is fundamentally based on a broad assessment of pedestrian streets. Research on pedestrian walkability assessment dates back to 1980 when J. Gehl first described the outdoor quality required for walking. Subsequently, various scholars have conducted research on pedestrian ratings, evaluating different factors influencing pedestrian behavior through different indicators [17]. Most of the research indicators focus more on easily accessible physical pedestrian environment indicators, such as land information and built environment [18,19]. Factors like climate and subjective human perception are often overlooked during the research process. Therefore, some scholars have used methods such as questionnaires and site visits to assess the walking space environment [20,21]. These methods directly capture pedestrians' subjective feelings. However, pedestrians from different backgrounds may have different needs and concerns about streets, leading to vastly different evaluations of the same street. With the advancement of computer performance and technology, large-scale quantitative studies have gradually emerged. For example, various indicators have been analyzed using a geographic information system platform to assess geographic landmark information [22]. The walkability and vitality of streets are comprehensively measured by collecting data from Point of Interest (POI), Baidu Street View, and Sina Weibo [23]. Machine learning algorithms are employed to quantify street space quality and determine the relationship between travel behavior and street space [24]. The semantic segmentation of street view images is used to identify the composition of different elements in streets [25]. These evaluation methods provide strong accuracy and comprehensiveness in measuring pedestrian space but often overlook pedestrians' subjective perceptions in practice.

2.3. Child-Friendly Influences

Research on the factors influencing child-friendly behavior based on AST has received considerable attention. The research mainly focuses on the relationship between built environment attributes and AST [26], as well as the influence of the social environment or policy factors on AST [27]. The evidence regarding the impact of the environment on child-friendly active school travel behavior is complex. Some studies suggest that features of the built environment, such as residential density, intersection density, street connectivity, mixed land use, sidewalk continuity and availability, and street lighting, can effectively promote friendliness [11]. However, other studies have found no significant relationship between residential density and AST [28], and a negative correlation between intersection density, street connectivity, and AST. This is because while increasing street connectivity enhances accessibility, it also complicates street networks, requiring children to cross more streets, thereby increasing traffic safety hazards and decreasing child friendliness [29]. Some studies comprehensively consider the influence of the social environment on child friendliness, such as students' ages, family incomes, family sizes, car ownership, and electric bicycle ownership, which to some extent determine the rate of AST. Additionally, research indicates that upstream policy choices also significantly influence the AST rate, with these social environments having a noticeable effect on increasing friendliness [30,31]. The current impact of urban environments on child-friendly AST has not been fully confirmed. Contradictory conclusions may stem from differences in urban development backgrounds, research methods, data processing, or the lack of scientific measurement systems for ASTS in some studies. Moreover, considering child-friendly factors only within individual regions may overlook regional differences [32].

Overall, there is limited research on the quality of ASTS. While both quantitative and qualitative studies exist, there is a lack of large-scale qualitative studies. Moreover, children's subjective perceptions are often underrepresented in quantitative studies of spatial quality, and research tends to focus on streets or schools as units of analysis, overlooking regional differences [31]. Addressing this research gap, this paper makes significant improvements in three aspects. Firstly, it extensively utilizes big data and data-processing techniques to overcome the limitations of evaluating the quality of urban street environments on a large scale [33]. Secondly, setting child-friendliness evaluation indicators at intermediate and detailed scales and adjusting the weight of these indicators based on children's perceptions through surveys significantly enhances the scientific rigor of studying school commuting path evaluation systems. Thirdly, it uses the comprehensive value of school commuting paths to reflect the child friendliness of school districts and examines the underlying driving mechanisms behind it.

3. Materials and Methods

3.1. Study Area and Data Acquisition

Lanzhou is one of the largest cities in the northwest region of China and serves as the political, economic, and cultural center of Gansu Province. Its primary education level ranks among the top in the province. However, there have been relatively few initiatives regarding the development of child-friendly cities (Figure 1). In 2022, there were 450 primary schools in the urban areas of Lanzhou, with a total of 253,800 enrolled students. This study focuses on the central urban areas of Lanzhou's traditional four districts. There are 151 primary schools within the study area, accounting for 34% of the total number of primary schools in the city, distributed as follows: 72 schools in Chengguan District, 40 schools in Qilihe District, 20 schools in Anning District, and 19 schools in Xigu District.

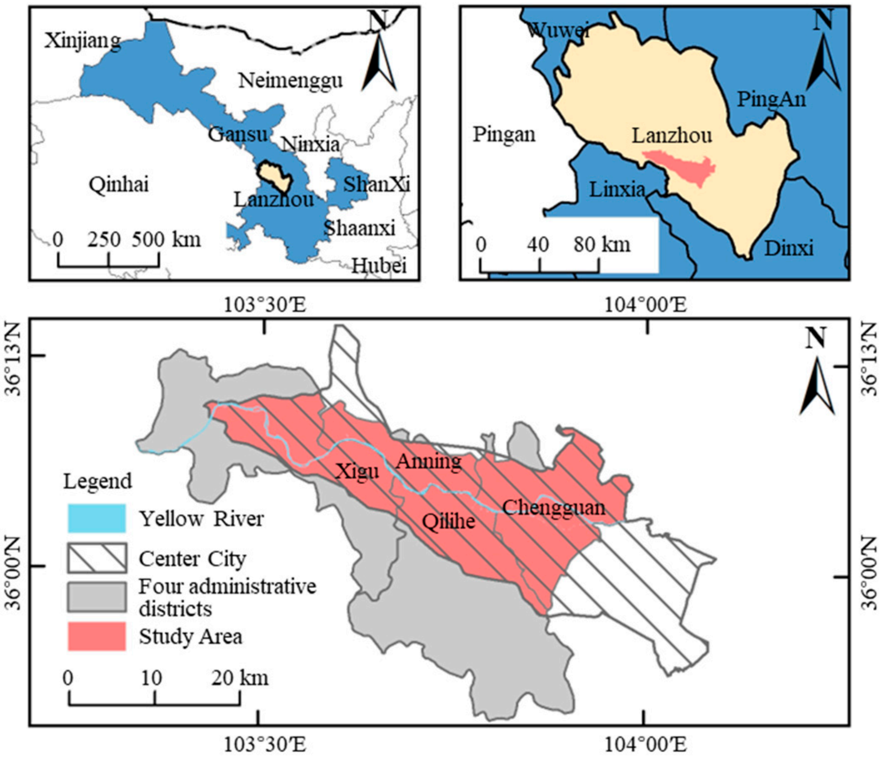


Figure 1. Location and extent of the study area.

The study data comprise physical spatial attribute data and social spatial attribute data. Physical spatial attribute data include ① primary school names and school district boundaries obtained from the Lanzhou Education Bureau's 2023 new student enrollment plan and zoning announcements; ② administrative divisions, rivers, and basic road data sourced from the 1:1,000,000 National Basic Geographic Database and Open Street Map (OSM); ③ primary school locations and residential area entrance/exit positions obtained from point-of-interest data provided by Amap (March 2023). Social spatial data include: ① commuting paths obtained through the Amap Path Planning 2.0 interface; ② attributes of spaces in front of schools obtained from survey photos and Baidu Street View (2020);

③ traffic congestion data at school entrances sourced from real-time Amap traffic data during peak commuting hours (7:20–7:50, 15:00–16:00).

3.2. Evaluation of ASTS

3.2.1. Construction of Walking Routes Network

Children's routes to and from school tend to favor the shortest road. Leveraging the pedestrian path API interface provided by China's largest map service provider, Amap, we constructed routes for commuting to and from school. These routes include information on time, distance, number of road segments, road attributes, and direction of travel. We computed routes from 1523 residential points within the school district to their respective schools, aligning attribute information with OSM road networks. After filtering and checking the path information, we obtained 1402 valid routes (Figure 2).

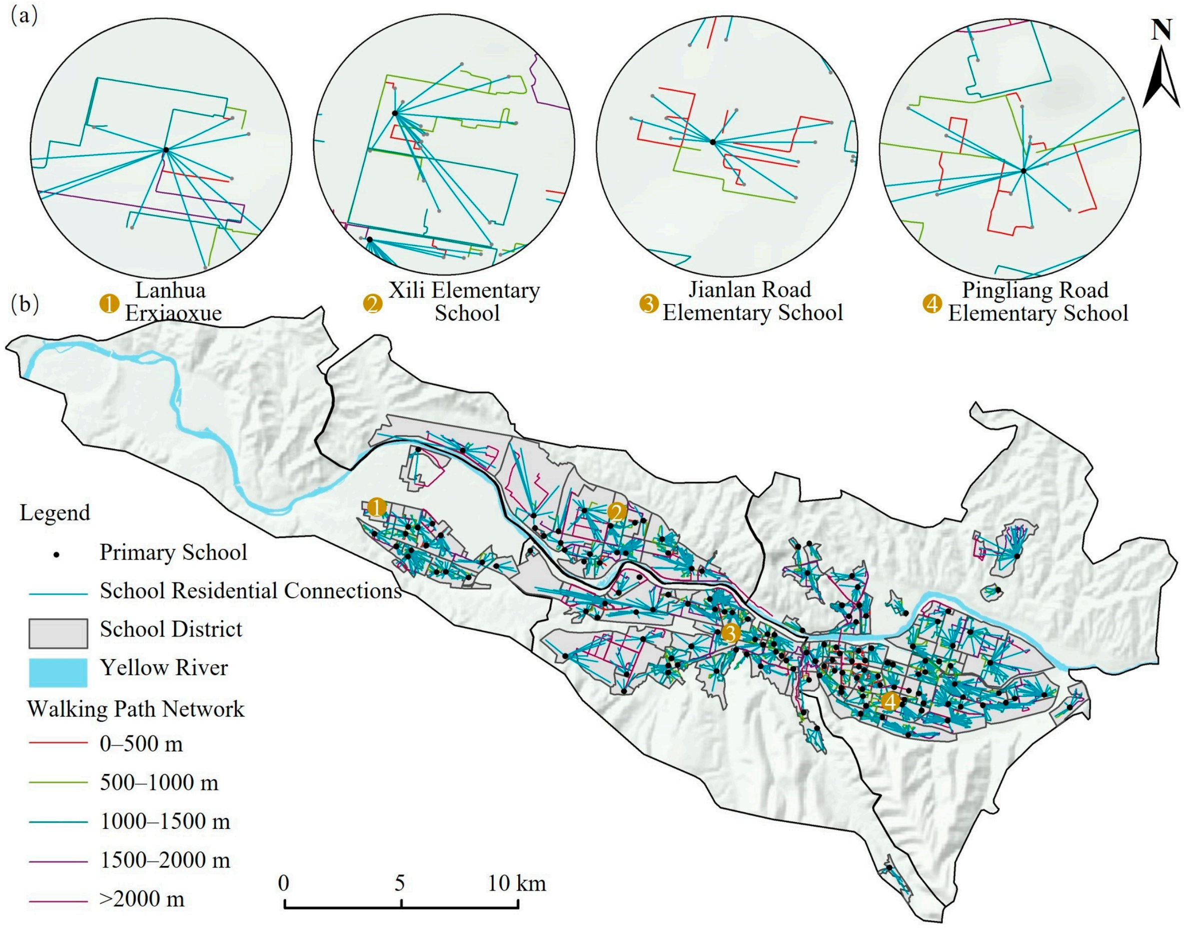


Figure 2. (**a**) Walking routes to and from school in surveyed elementary schools; (**b**) walking route network for elementary school students in the central urban area of Lanzhou city.

3.2.2. Linear Measurement of ASTS at the Mesoscale

Intermediate-scale ASTS comprises route attributes obtained primarily from API interfaces and road network attributes reflecting urban spatial structure. It comprises connectivity, depth, choice, integration, and other comprehensible morphological variables. Calculations are conducted using DepthmapX based on OSM road data, with the following calculation formulae [34,35].

① Connectivity:

$$CO_i = k \tag{1}$$

k represents the number of direct connections a road segment has with other roads.

② Depth:

$$TD_i = \sum_{j=1}^{n} d_{ij} \tag{2}$$

TD_i denotes the depth of the i-th node, while d_{ij} represents the shortest topological distance between any two points i and j in the connectivity graph.

③ Choice:

$$CH_i = \frac{CO_i}{TD_i} \tag{3}$$

CH_i represents the degree of choice at the i-th node

④ Integration:

$$I_i = \frac{1}{ARR_i}ARR_i = \frac{AR_i}{D_n}AR_i = \frac{2(MD_i - 1)}{n-2}D_n = 2n\left(log_2\left(\frac{n+2}{3} - 1\right) + 1\right)/(n-1)(n-2)MD_i = \frac{TD_i}{n-1} \tag{4}$$

ARR_i represents the actual asymmetry value of element i, AR_i denotes the relative asymmetry value of element i, D_n indicates the normalization parameter, TD signifies the total depth, which is the sum of the shortest topological distances from each element to all other elements, and MD represents the mean depth.

3.2.3. Node Measurement of ASTS at the Microscale

School-front spatial evaluation includes the street space within a 200 m radius of the school gate and the elements of the school-front space. The quality assessment of the school-front space utilizes a method combining street view images (SVIs) and image recognition technology [35]. The cityscape dataset is utilized to annotate street view image results, with Dense Semantic Segmentation dividing street view images into 30 categories [36]. Elements in the street view, such as flat surfaces, humans, vehicles, and constructions, are identified, and the proportion of specified elements to total image elements is calculated (Figure 3).

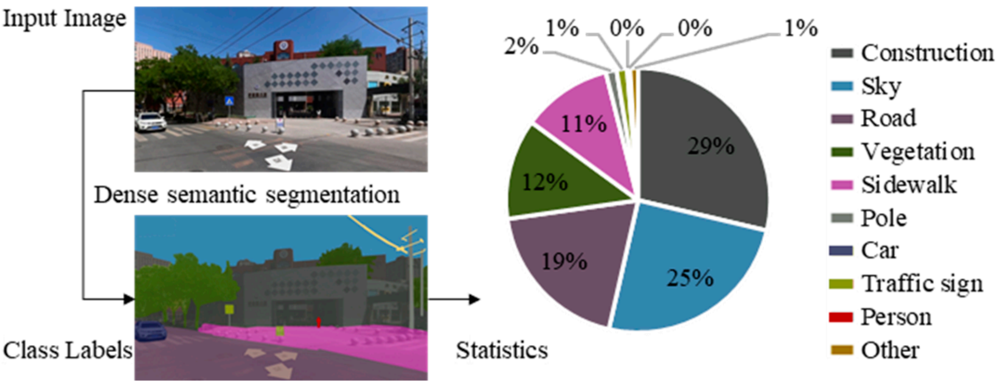


Figure 3. Measurement method of school pre-space quality at microscale.

3.2.4. Comprehensive Assessment of ASTS

Research assessing child friendliness predominantly centers on children's commuting requirements, encompassing safety, enjoyment, and comfort during the commute. [9,37,38]. Drawing on existing research and the specific characteristics of the study area, this paper is structured into three system layers: accessibility, safety, and comfort. Further subdivision based on school commuting path characteristics includes two criteria layers: linear space and nodal space. Evaluation indicators and measures are detailed in Table 1.

Table 1. Evaluation indicator system and results.

System Layer	Criteria Layer	Indicator Layer	Meaning of Variables	Measurement of Variables	Weight
Accessibility (0.301)	Road accessibility	Connectivity	Number of connections to other roads for this section	Sum of connectivity values for each segment of roads between school and residential area	0.033
		Choice	Difficulty level of selection for this Section in the entire road network	Sum of selection degree values for each segment of roads between school and residential area	0.031
		Integration	Difficulty level of reaching this section in the entire road network	Sum of Integration degree values for each segment of roads between school and residential area	0.063
	Schoolfront space accessibility	Road congestion	Congestion within 200 m range of the school gate during peak school hours	Using Amap road condition prediction module, rate smoothness as follows: smooth = 4, good = 3, congested = 2, very congested = 1	0.087
		Number of Intersections	Number of intersections within 100 m of the school front	Use ArcGIS to make a 100 m buffer with the school entrance and count the number of intersections in the buffer.	0.039
		Relative pedestrian width	Actual utilized width of the straight pedestrian walkway in front of the school	Calculate the percentage of remaining effective width after objects such as transformer boxes, utility poles, and vehicles occupy the roadway, relative to the total road width	0.048
Safety (0.357)	Road safety	Pedestrian space continuity *	Continuity of pedestrian walkways in the commuting path	Calculate the percentage of the total path length after removing the length of crosswalks, underground passages, pedestrian overpasses, and stairs from the road path	0.070
		Pedestrian crossing facilities *	Number of pedestrian crossing facilities in the commuting path	Count the number of pedestrian crossing facilities, assign different scores to different types: underground passages = 2, stairs = 1, crosswalks = −1	0.065
		Number of turns *	Number of turns in the commuting path	Count the number of direction changes in the commuting path	0.080
	Schoolfront space safety	Schoolfront roads *	Road grade of the road facing the school gate	Using OSM data, classify schoolfront roads into: side roads = 3, minor roads = 2, main Roads = 1	0.051
		Traffic calming measures	Traffic calming facilities at the school gate	Based on investigative, Evaluate the quantity of design elements aimed at reducing vehicle speed, including pavement (color, guide lines, crosswalks, etc.), facilities (speed bumps, signs, etc.), and elevation changes (curbs, flower beds, etc.).good = 4 (>6), suitable = 3 (5–6), average = 2 (3–4), poor = 1 (≤2)	0.037
		School gate buffer zone	Size of the buffer zone at the school gate	Based on investigative, rate the buffer zone area: adequate = 4, suitable = 3, average = 2, poor = 1	0.053
Comfort (0.342)	Road comfort	Commuting distance *	Actual distance of the commuting path	Calculate the actual distance of the commuting Path	0.100
		Depth *	Minimum number of times needed to reach other sections from this section	Sum of depth values for each segment of roads between school and residential area	0.039
		Detour ratio *	Detour level of the commuting path	Ratio of actual commuting path length to Euclidean distance	0.053
	Schoolfront space comfort	Interface diversity	Types and quantity of visual elements at the school gate	Based on investigative, rate the appearance of decorative signs, exhibition boards, etc.: suitable = 3, average = 2, poor = 1	0.020
		Waiting space	Area for parents waiting for students at the school gate	Based on investigative, score the size of the waiting space for pick-ups and drop-offs and the facilities available for resting, such as benches: suitable = 3, average = 2, poor = 1	0.109
		Parking organization	Temporary parking organization at the school gate	Rate the temporary parking area: adequate = 4, suitable = 3, exists but insufficient = 2, none = 1	0.021

* Indicators are negatively correlated.

The weighting is performed through a combination of objective and subjective methods. Objectively, the entropy method is employed to calculate the weights of each indicator. The calculation steps and formulas are as follows [39]. To avoid overly subjective weighting using the entropy method, one school was randomly selected from each of the four districts (Lanhua Second Primary School, Xili Primary School, Jianlan Road Primary School, and

Pingliang Road Primary School) for a survey of children who commute home independently after school. Considering children's limited cognitive abilities, the survey on path friendliness was simplified to focus on commuting routes to and from school and ranking the importance of safety, comfort, and accessibility across six criteria layers including path and school-front spaces. Considering the limited cognitive abilities of children, the investigation of path friendliness was simplified to validate school commuting routes. The study compared the relative importance of safety, comfort, and accessibility among six criteria layers, including paths and school-front spaces. We collected 107 valid survey responses covering simulated routes from four elementary schools. The table values indicate how many respondents deem one element more important than another (Table 2). Weight calculations used the Analytic Hierarchy Process to assess the importance between two elements: scoring 2 if A is more important than B, 0.5 if less, and 1 if equally important. The weights of the criteria layers in the comprehensive evaluation are the average values derived from the entropy method and the Analytic Hierarchy Process. The revised weights for evaluation are presented in Table 1.

$$X_{ij} = \begin{cases} \frac{X_i - X_{min}}{(X_{max} - X_{min})} + 0.01 \ \ (a) \\ (X_{max} - X_i)/(X_{max} - X_{min}) + 0.01 \ \ (b) \end{cases} P_{ij} = X_{ij} / \sum_{i=1}^{n} X_{ij} E_j = -\frac{1}{lnn} \sum_{i=1}^{n} P_{ij} \times lnP_{ij} G_j = 1 - E_j W_j = G_j / \sum_{j=1}^{n} G_j \quad (5)$$

X_i represents the original data, X_{min} represents the minimum value of the indicator, and X_{max} represents the maximum value of the indicator. Equation (a) is utilized for calculating the forward indicator, while Equation (b) is employed for computing the reverse indicator. P_{ij} signifies the weight of the indicator, E_j denotes entropy, G_i represents the coefficient of entropy variation among the sub-indicators of the *j*-th indicator, and W_j denotes the weight of individual indicators.

Table 2. Importance and weights of criteria layer.

	Road Accessibility	Schoolfront Space Accessibility	Road Safety	Schoolfront Space Safety	Road Comfort	Schoolfront Space Comfort	Weight
Road accessibility	-	21	21	43	21	30	0.098
Schoolfront space accessibility	86	-	34	64	34	51	0.193
Road safety	86	51	-	64	39	60	0.215
Schoolfront space safety	43	30	30	-	26	43	0.123
Road comfort	86	51	47	73	-	64	0.230
Schoolfront space comfort	60	34	30	43	30	-	0.141

3.3. Correlation Analysis of Route Friendliness

We used the Geographic Detector model to assess the factors influencing the development of ASTS friendliness. The dependent variable is the friendliness of ASTS, defined as the average friendliness of children's commuting paths to all primary schools in the school district. The selection of the independent variables is based on the relevant literature [11,40,41], primarily categorized as the built environment and the social environment. The built environment comprises the district's inherent attributes and closely related land use, while the social environment primarily encompasses economic factors, population demographics, and the concentration of elementary schools. The specific types of variables and their outcomes are detailed in Table 3.

Table 3. Descriptive statistics of independent variables.

Influencing Factor	Variable	Definition	Units	Mean	Standard Deviation
Built environment	X1 School district Scale *	School district area	km^2	0.911	1.134
	X2 School Centrality *	Straight-Line distance between school location and geometric center	km	0.688	0.308
	X3 Environmental Comfort	Ratio of green area to school district area	%	34.430	4.237

Table 3. *Cont.*

Influencing Factor	Variable	Definition	Units	Mean	Standard Deviation
	X4 Transportation Convenience	Ratio of road length to school district area	km/km^2	6.391	1.489
	X5 Land Use Diversity	Mixed status of POI within school district	-	0.873	0.620
	X6 Land Development Intensity	Ratio of building footprint area to school district area	%	9.108	3.675
	X7 School Frontage Area	Street view image recognition	m^2	139.230	2.421
Social environment	X8 Economic Intensity	Average housing price within school district	$10{,}000\ RMB/m^2$	0.978	0.465
	X9 Population Density	Average population within school district	$10{,}000\ person/km^2$	0.362	0.289
	X10 Agglomeration	Cold-Hot Spot analysis calculation in ArcGIS	-	1.013	0.324

* Factors are negatively correlated.

4. Results and Analysis

4.1. Walking Routes Network Analysis

4.1.1. Linear Characteristics of ASTS

The ASTS linear space computation results are depicted in Figure 4. The accessibility analysis reveals an average connectivity of 44.4, an average selection degree of 31.1, and an average integration degree of 0.7 for school commuting paths, yet these values alone do not adequately reflect the network's overall accessibility. Urban road network structure is employed to gauge the accessibility level of school commuting paths. According to the "China Key Cities Road Network Structure Portrait Report" published by the Ministry of Public Security's Road Traffic Safety Research Center, Lanzhou's road network level falls below the national average for key cities. Lanzhou's road network connectivity measures 3.22, which is lower than the average of 3.28 for 36 key cities. The density of dead-end roads is 5.7/100 km^2, exceeding the average of 5.55/100 km^2 for key cities, indicating comparatively weaker overall accessibility of school commuting paths in Lanzhou.

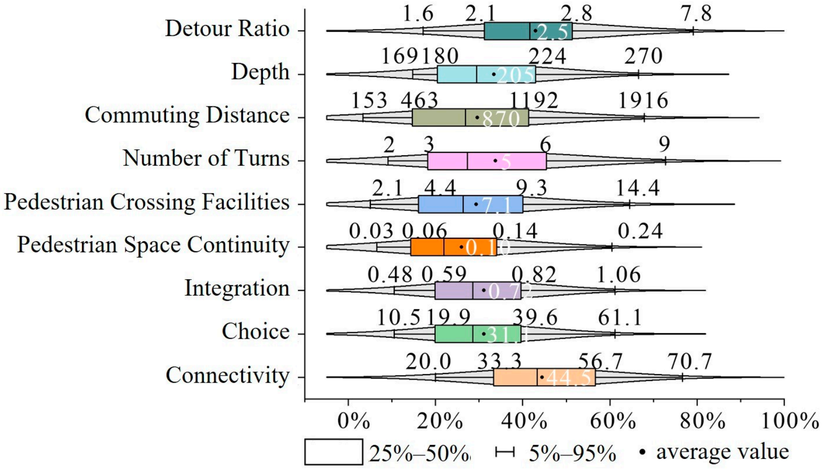


Figure 4. Linear spatial evaluation calculation results.

The results of road comfort show that the average path distance in the path network is 870 m, 86.23% of the paths are less than 1500 m, and 69.40% of the paths are less than 1000 m, which indicates that most students can reach school on foot in 15 min, which is basically in line with the principle of the layout of the 15-min living circle. However, more than 7.21% of the paths have a length of more than 2000 m, which is a significant barrier for this group of students to walk to and from school. Comparing the straight-line distance between home and school, the average straight-line distance is 575 m, which exceeds the requirement of a 500 m service radius of the elementary school, and the average detour ratio is 2.5, which is larger, reflecting that the road network structure is not perfect and the penetration of the road to the area, as well as the neighborhood scale division, is still insufficient. In addition to the influence of the Lanzhou belt topography, paths with longer straight-line distance addresses are often located on the east and west sides of the school, and according to Chang-Deok Kang's research results, a 500 m distance of the walking path network circular structure is better, while more than 1000 m after higher circular flatness is more unfavorable to pedestrian travel [42].

Commuting path safety analysis reveals that the road network typically involves 2–8 turns, with an average of 5 turns. The higher the number of turns, the greater the potential risk of children getting lost on the path. Additionally, Rounaq Basu suggests that each turn reduces walking willingness by 34.4 m [43]. This negative willingness can significantly affect commuting paths of approximately 1 km. The average continuity of school commuting paths is 93%. While this figure is high, close to half of these paths have a continuity of 100%, implying that many children still encounter complex traffic conditions in reality. Among the 762 paths in the walking routes network, 54% contain pedestrian crossing facilities. There are notable incidences of pedestrian–vehicle conflicts during school commutes, highlighting the need to enhance the safety of school commuting paths.

4.1.2. Node Characteristics of ASTS

The spatial computation outcomes for campus nodes are illustrated in Figure 5. The accessibility analysis reveals that among the 151 primary schools studied, 5 schools experience severe congestion at dismissal, 17 schools are moderately congested, 50 schools exhibit congestion, and 78 schools have smooth traffic flow. Nearly half of the schools experience congestion at dismissal times. The "Regulations on the Setting of Road Traffic Facilities around Primary and Secondary Schools and Kindergartens" issued by the Ministry of Public Security suggests that school entrances should be located at least 100 m away from intersections. However, in Lanzhou, the entrances of 116 schools are within 100 m of intersections, and 53% of schools have more than one intersection within this range. Although intersections provide convenience for traffic flow, they also increase risks for commuting paths. The average width of commuting paths in front of schools is 3.2 m, with effective pedestrian space accounting for 77%. However, this space is often encroached upon by illegal parking, commercial displays, vendors occupying sidewalks, electrical boxes, and advertising billboards, leading to congestion in commuting spaces.

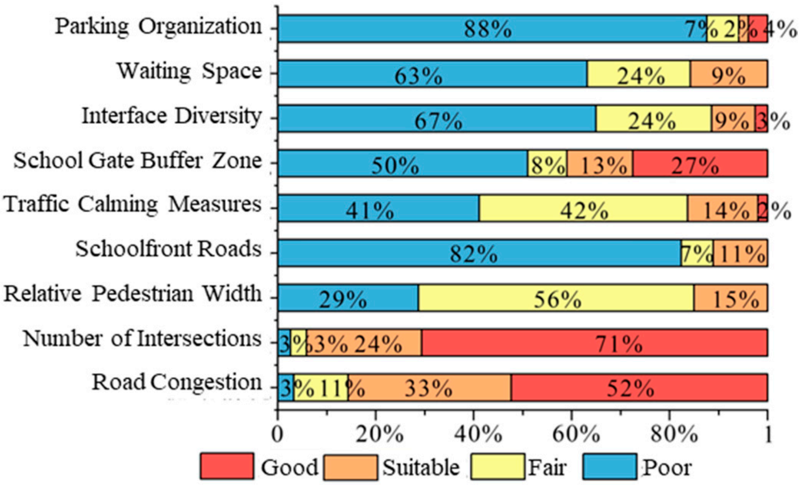


Figure 5. Node spatial evaluation calculation results.

The safety assessment of school-front spaces indicates that in Lanzhou, the entrances of primary schools face different road grades. The "Regulations" suggest that primary schools should not be located on urban arterial roads. However, 17 schools have entrances facing urban arterial roads, 10 face urban side roads, and 124 face internal roads, indicating a scarcity of schools facing higher-grade roads. Through an evaluation of static stabilization facilities in front of schools, it was found that the emphasis on such facilities varies among different schools. In the Anning district, almost all schools have at least one static stabilization facility, while in the other three districts, only about half of the schools have them. Based on actual surveys, school-front buffer zones were categorized as transit areas, parent waiting areas, and child waiting areas. It was found that the size and function of most school-front spaces are insufficient. More than half of the primary schools lack child waiting areas, and schools located on internal roads often utilize community streets for their front spaces.

Regarding comfort, over half of the school-front spaces have promotional facilities such as posters and bulletin boards at the entrance. However, these are mostly used for school enrollment promotion, lacking diversity in facilities and colors. There is a lack of child-friendly facilities such as exhibition pavilions and recreational facilities. Additionally, 63% of primary schools lack areas specifically designated for parent waiting. Furthermore, there are almost no areas designated for temporary parking for parents picking up or dropping off students, resulting in a shortage of space for children to walk due to the lack of parent waiting areas and motor vehicle parking spaces.

4.2. Comprehensive Evaluation of Child Friendliness

4.2.1. Spatial Distribution Characteristics

After computing the ASTS, the average value is obtained for each district. The amalgamation of multiple pathways within the same district to some extent can effectively reflect the district's child friendliness. The evaluation results are categorized into five classes using the natural breaks method (Figure 6). The quantities of school district friendliness from high to low are 20, 26, 39, 41, and 25. Overall, the friendliness of school districts towards children is moderate. Apart from Xigu District, the distribution of different levels of friendliness across the other three districts is relatively consistent. Xigu District exhibits lower overall child friendliness, with 63% of its districts rated as low or very low in friendliness. Anning District's performance is marginally superior to Chengguan District and Qilihe District. Approximately half of the school districts have a friendliness rating of good or higher, indicating a correlation between child friendliness and urban characteristics and development timelines. Xigu District, being the primary industrial hub of Lanzhou with a substantial industrial landmass, experiences lower friendliness due to factors like large block sizes and inadequate school-front spaces. Anning District, a comparatively late-developing area in Lanzhou, boasts a more comprehensive and technologically advanced infrastructure. Moreover, the inherent attributes of affiliated primary schools associated with numerous universities in the district contribute to significantly higher safety scores compared to other regions. Hence, overall, primary school friendliness in Anning District surpasses that of others.

Spatial analysis reveals a distinct "core–periphery" pattern in the school district friendliness of Lanzhou's central urban area. Districts with high child friendliness cluster around Xijin East Road in Qilihe District and Qingyang Road in Chengguan District, which are relatively central areas with superior infrastructure. The compactness of schools leads to smaller district areas, and their peripheries exhibit greater regularity due to road network division. Conversely, regions with lower friendliness are typically situated on the peripheries of each district. These areas face challenges such as larger service areas and reduced accessibility due to dead-end streets and T-shaped intersections on the urban periphery. School districts undergo shape distortions to accommodate larger populations. In essence, smaller district areas, higher centrality, more comprehensive infrastructure, and regular peripheries correlate with better child-friendly commuting routes.

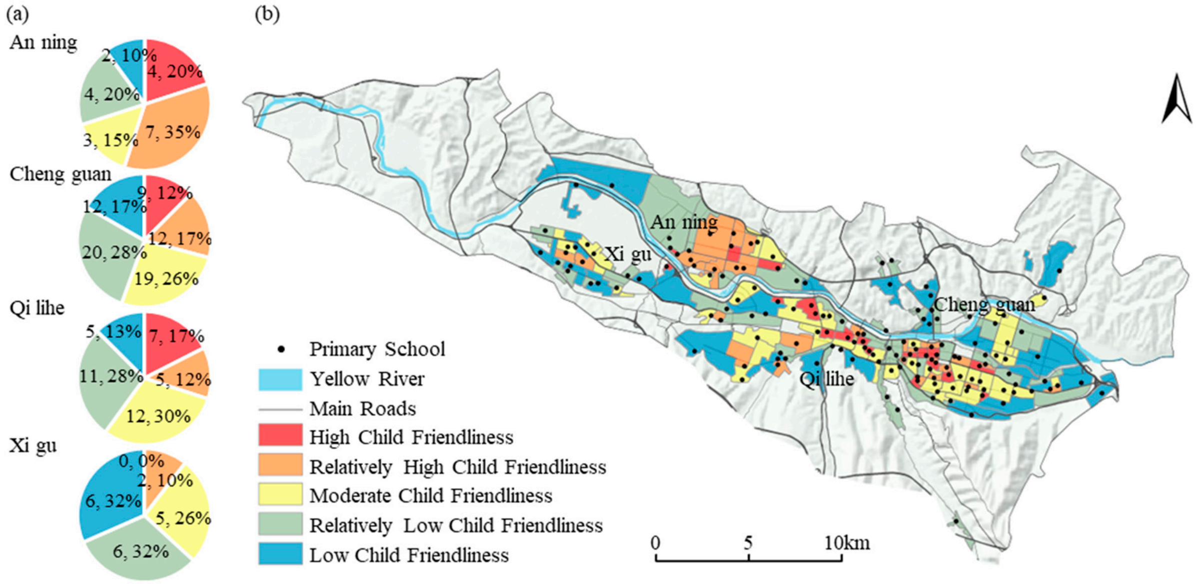


Figure 6. (**a**) Number and percentage of different levels of friendliness in the four administrative districts; (**b**) Spatial distribution of different levels of friendliness.

4.2.2. Classification and Characteristics

The ternary plot illustrates the classification tendencies of each primary school across three system layers, as depicted in Figure 7. High friendliness scores predominantly cluster around the centroid of the triangle, indicating that school districts with high friendliness exhibit favorable performance across the dimensions of accessibility, safety, and comfort. These indicators primarily range between 0.25 and 0.75, 0.25 and 0.625, and 0.375 and 0.75, with higher friendliness tending towards regions emphasizing greater comfort. Conversely, low friendliness is concentrated at the triangle's vertices, reflecting that a particularly low score in any of these dimensions prevents overall improvement in friendliness, underscoring the need for integrated planning considerations. Furthermore, no data fall in the region where comfort scores are below 0.125 and safety scores are below 0.5, underscoring the minimal requirements that friendliness ratings have for safety and comfort.

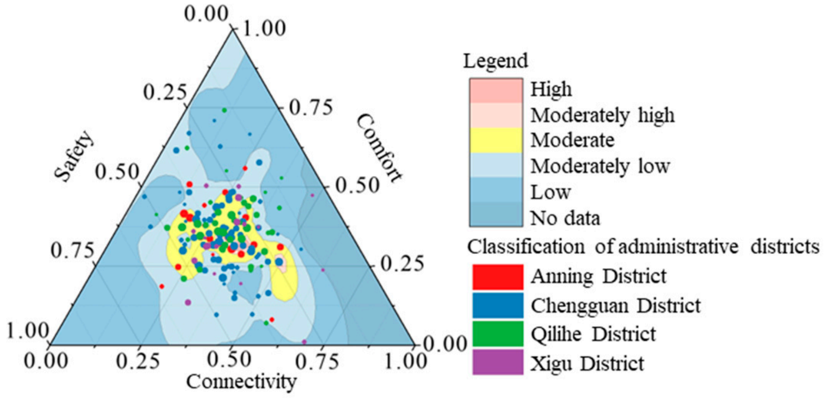
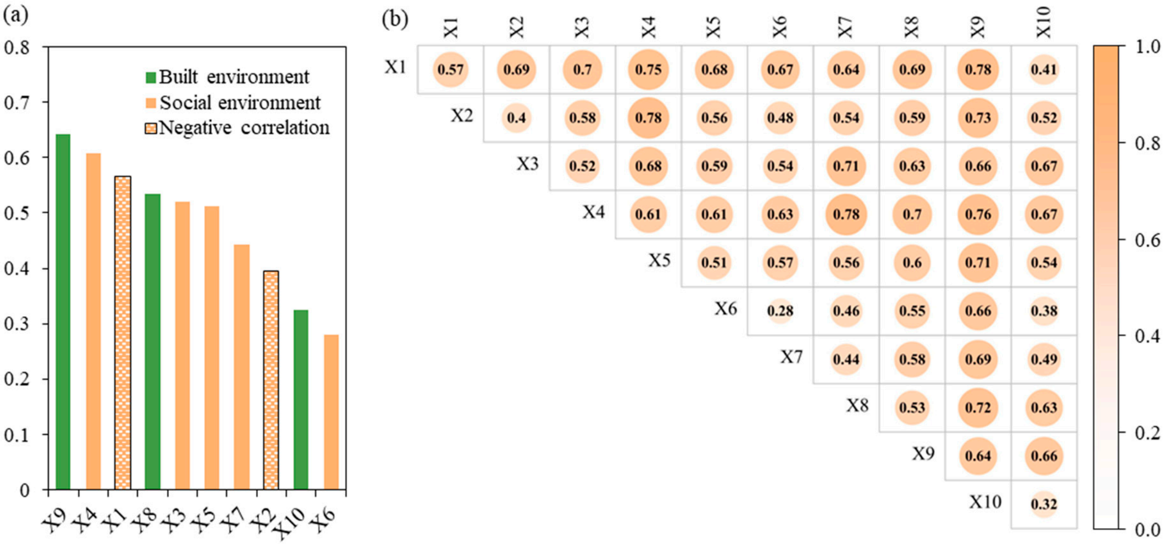


Figure 7. Distribution of child-friendliness ratings.

From the administrative area, each district exhibits different inclinations in the criteria used to assess friendliness. Xigu District has notably lower transportation connectivity. Anning District emphasizes high levels of safety and comfort. Chengguan District shows varying accessibility levels with a strong emphasis on comfort. Qilihe District maintains relatively balanced indicators across all aspects without significant weaknesses. Overall trends align consistently with earlier discussions on the correlation between child friendliness, urban characteristics, and the timeline of urban development.

4.3. Factors Influencing Friendliness

The results using the Geodetector model are shown in Figure 8. Population density and transportation convenience have a significant positive impact (>0.6) on child friendliness. The population directly influences the provision of primary schools, as according to the "Standards for Urban Residential Area Planning and Design", residential areas with populations of 15,000–25,000 must be equipped with primary schools. The greater the number and more evenly distributed the primary schools are, the more they can significantly reduce students' commuting distances. The "time–space compression" benefits brought by transportation convenience directly shorten the length of the commuting path, and areas with strong transportation convenience can bring better effects in terms of both accessibility and comfort on the commuting path.



	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10
X1	0.57	0.69	0.7	0.75	0.68	0.67	0.64	0.69	0.78	0.41
X2		0.4	0.58	0.78	0.56	0.48	0.54	0.59	0.73	0.52
X3			0.52	0.68	0.59	0.54	0.71	0.63	0.66	0.67
X4				0.61	0.61	0.63	0.78	0.7	0.76	0.67
X5					0.51	0.57	0.56	0.6	0.71	0.54
X6						0.28	0.46	0.55	0.66	0.38
X7							0.44	0.58	0.69	0.49
X8								0.53	0.72	0.63
X9									0.64	0.66
X10										0.32

Figure 8. (**a**) Explanatory power of factors influencing friendliness; (**b**) explanatory power of friendliness under the synergy of two-factor interactions.

Economic strength, environmental comfort, and land use diversity have a strong positive effect on improving the friendliness of commuting routes (>0.5). The housing prices around schools reflect, on one hand, the centrality of schools in the city, and on the other hand, the economic foundation determines the investment in urban infrastructure, indicating that areas with high child friendliness in commuting paths still tend to be areas with better infrastructure, such as the city center. Environmental comfort and land use diversity are more reflected in their environmental effects. The former measures the quality of the city's natural environment, while the latter reflects the ability to enjoy a more diverse life experience in the area. This indicates that high-quality natural environments and abundant facilities around schools can provide students with a more comfortable and convenient commuting environment.

The size of the school front area, school agglomeration, and land development intensity have a certain positive effect on the friendliness of children's commuting routes. A larger school-front area can accommodate more facilities, including those required for parking and leisure spaces for parents waiting or students interacting. The impact of land development on the friendliness of commuting routes is relatively complex. High development intensity may lead to more buildings, restricting commuting routes. Areas with high development intensity may experience large flows of people and vehicles, leading to traffic congestion and safety risks. Additionally, high-intensity land development results in fewer open spaces and green landscapes, leading to poorer comfort on commuting routes.

The size of the school district and the centrality of schools have a negative effect on the child friendliness of commuting routes. A larger school district means a larger service range for schools, directly leading to an uneven distribution of resources. Students need to spend more time and travel longer distances to reach schools. The increase in commuting route length increases the likelihood of students facing risks, directly reducing the friendliness in terms of convenience and safety. The centrality of schools is similar to the size of the school district. Lanzhou's unique strip-shaped terrain results in most school districts having an east–west structure. There are certain differences in the friendliness of commuting to school between students in the north–south and east–west directions. Additionally, some schools are located on the edges of the school district, making it difficult to serve the entire area well. A more scientific approach is needed to delineate school districts.

In the context of interactions between paired factors, the explanatory capacity for child-friendliness is enhanced compared to individual factors. The correlations among different factors vary, indicating that child friendliness is influenced by the combined effects of multiple factors, with variations in how these factors interact with each other. The joint effect of transportation convenience and the school-front area becomes the strongest combination for explaining child friendliness (0.785). Additionally, the interaction between transportation convenience and the centrality of primary schools, population density, and the size of the school district exceeds 0.7, indicating that transportation convenience is the first factor to consider in the construction of child-friendly commuting routes. Due to the strong explanatory power of population density for child friendliness, the overall explanatory power is further enhanced when it interacts with other factors, making the interaction between population density and other factors an important means to improve child friendliness. The concentration of primary schools and their combined interaction with other factors still have relatively weak explanatory strength for child friendliness. The combined explanatory strength with school district size and intensity of land use is approximately 0.4. This suggests that improvements in child friendliness are not strongly influenced by school density, and the combination of land development intensity with other factors also has limited explanatory power for child friendliness.

5. Discussion and Conclusions

In the context of developing child-friendly cities, our study focuses on how urban environments affect the child friendliness of school commutes. Initially, we examined commuting routes to 151 public primary schools in downtown Lanzhou. These routes were simulated using the Amap API, starting from residential areas and terminating at schools. We evaluated the path network from both macroscopic and microscopic perspectives. Macroscopic evaluations focus on route characteristics, while microscopic assessments target the environmental quality around school entrances. Subsequently, we analyzed school districts as units to assess the child friendliness of school commutes, exploring the impact of social and built environments. Scientifically evaluating the ASTS presents challenges, so we employed a multidimensional approach using various indicators to comprehensively evaluate child-friendly commuting environments. This study aids in evaluating and enhancing school commuting environments and provides insights for urban planning and management.

5.1. A Potential Complement to Asts Measurements

The core of evaluating the child friendliness of school commutes (ASTS) revolves around addressing two main challenges: firstly, determining the specific commuting routes for children, and secondly, scientifically assessing the friendliness of ASTS. Current research predominantly relies on actual travel surveys for the first challenge, which are labor-intensive and challenging to scale up for comprehensive studies [44]. Furthermore, using ArcGIS to generate the shortest school commuting routes results in an overlap of only 46.7% to 64.3% with actual travel routes, which is insufficiently accurate [45]. Therefore, we refined our approach to route acquisition. We utilized the pedestrian route interface provided by Amap, China's largest map service provider. This interface allowed us to simulate school commuting routes using residential areas and schools as the start and end points for walking navigation. Such simulations facilitate large-scale studies and significantly reduce survey workload while enhancing route accuracy and information fidelity. Addressing the second issue, our literature review enriched the depth and diversity of evaluation indicators. We initially assigned weights to these indicators using the entropy method, followed by refining these weights through sampling surveys. In evaluating ASTS, we adjusted the weights of evaluation indicators through research to align the evaluation results with reality as much as possible [46]. Despite our extensive efforts in the evaluation process, there remains ample room for improving ASTS assessment in the future. This is because research systems designed by different regions and authors may vary. For instance, Xu Zhen found significant disparities between school districts in Jianye District, Nanjing, based on indicators such as the straight-line distance from home to school, path distance, and potential exposure risk, with a considerable portion of the school districts failing to meet standards [47]. Mojtaba Khanian utilized visibility analysis to quantify the green spaces between homes and schools, discovering that approximately 48% of spaces within 10 m of visibility along the route were green, and he linked green spaces to social equity [44]. Huo Haiying examined the surrounding environment of primary schools in Shijiazhuang from perspectives of safety, comfort, and interest, finding that people's satisfaction with the current commuting space environment was generally rated average [38]. While these assessment methods generally possess scientific validity, the differing dimensions and methodologies of evaluation make it challenging to horizontally compare cities across regions. Thus, exploring a set of universal evaluation methods remains worthwhile.

5.2. More Effective Ways to Improve Friendliness Based on Findings

The assessment of child friendliness and the findings on driving mechanisms offer valuable insights and lessons for crafting interventions and spatial adjustment strategies related to child-friendly policies. Firstly, our analysis reveals a general deficiency in the overall child friendliness of school routes across Lanzhou City, marked by pronounced spatial disparities and inadequate school district arrangements, as well as insufficient pre-school spatial facilities and functionalities. In light of this, governmental intervention should actively steer the development of child-friendly cities, optimizing the layout of school districts and undertaking appropriate renovations of pre-school spaces. These measures can yield immediate improvements in friendliness, emphasizing the significant effort required to enhance commuting spaces for children. Secondly, factors such as population density and transportation accessibility emerge as critical determinants of child-friendliness. The rising population density necessitates an increase in the number of accompanying schools, prompting local authorities to regulate population density judiciously to ensure adequate school provisions. The tangible impact of transportation accessibility underscores the importance of prioritizing infrastructure development, including the removal of dead-end roads and the refinement of road networks. Lastly, the influence of land development intensity on friendliness appears to be minimal, in contrast to some research findings. This discrepancy may be attributed to Lanzhou City's geographical setting within a valley, where high land development intensity results in marginal disparities across regions, consequently diminishing the explanatory power of child-friendliness. In summary, enhancing child-friendliness constitutes a multifaceted endeavor requiring concerted government efforts to address both built and social environments concurrently, thereby enhancing the schooling experiences of children.

5.3. Conclusions

The primary goal of this study was to assess the quality of ASTS and identify key factors influencing school district friendliness. Utilizing a variety of data sources and advanced big data analytics, this study developed a comprehensive evaluation framework.

The methodology significantly reduced subjectivity and survey workload, enhancing the reliability of the findings.

This study focused on primary schools in Lanzhou's central urban area to evaluate the city's ASTS. We observed a notably low quality of ASTS, attributed to subpar road networks and poorly planned school district boundaries. This resulted in inefficient routes characterized by longer commutes, excessive detours, and frequent turns. Additionally, the quality of ASTS varied considerably across different areas. Among the four administrative districts, Anning District performed the best, followed by Chengguan, Qilihe, and Xigu. The distribution of school district friendliness followed a core–periphery pattern: smaller, well-developed infrastructure districts were more favorable, whereas larger, irregularly shaped districts with schools located far from the district center were less so.

When enhancing child friendliness in school districts, comfort is more critical for ASTS evaluation than the other two dimensions. This underscores the need for scientifically organizing school zones and thoughtfully designing the spaces surrounding school entrances. Additionally, eight factors positively influenced friendliness levels. Most notably, population density and transportation convenience had the strongest positive impact (scoring 0.6), followed by economic robustness, environmental comfort, and diversity in land use (scoring 0.5). Conversely, the size of areas in front of schools, school density, intensity of land development, and both the scale of school districts and the centrality of schools negatively affected friendliness. The enhanced interaction between two factors suggests that adopting multiple perspectives is more effective in increasing the child friendliness of school districts.

In conclusion, this paper evaluated ASTS and examined how various urban environments impact the friendliness of school districts. However, the study has several limitations. First, there is currently no agreed-upon framework for evaluating ASTS within the academic community, and more research is needed to refine assessment methods across different cities. Second, the study did not account for specific attributes such as school size, founding date, and student demographics, which could influence the findings. Future research should address these aspects to provide a more comprehensive understanding. Lastly, while this study highlights the relationship between child friendliness in school districts and urban environments, it does not establish causation. Further research is required to explore the underlying mechanisms of their interaction.

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