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Research Article

Impacts of the Feeder-Related Built Environment on Taxi-Metro Integrated Use in Lanzhou, China

Qixiang Chen, Bin Lv, Binbin Hao, and Xianlin Li

School of Traffic and Transportation, Lanzhou Jiaotong University, Lanzhou 730700, China

Correspondence should be addressed to Bin Lv; jdlbxx@mail.lzjtu.cn

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It is very common that taxi is used as a feeder mode to/from a metro station especially in third-tier cities of China. But research on taxi-metro integrated use is rather limited. This paper investigates the relationship between feeder-related built environment and taxi-metro integrated use by using taxi trajectory data in Lanzhou, China. Firstly, regression models are developed to explore the transfer distance of access/egress trips during peak hours. Then, the catchment area is delineated for collecting feeder-related environment variables. Finally, several negative binomial regressions are employed to examine the relationships between feeder-related built environment and taxi-metro integrated use during peak hours on weekdays. The results reveal that (a) people prefer to use taxi as feeder mode for metro access during morning peak hours and for metro egress during evening peak hours; (b) the transfer distance of taxi-metro integrated use is about 3.8 km; (c) higher mixed land use generates more taxi-metro integrated use during evening peak hours. Higher proportion of residential land use attracts more taxi-metro integrated use for metro access during morning peak hours. Those findings will help transport planners to develop tailored land-use interventions to improve transit accessibility and promote the sustainable multimodal travel.

1. Introduction

As an economically feasible and environmentally friendly travel mode, metro system is considered the natural backbone of sustainable transportation systems, stimulating passengers to switch from personal motorized transportation to rail transportation, and has gained increasing popularity and attracted much attention from policymakers and researchers [1–4]. However, metro system provides station-to-station services and cannot cover every corner of a city. General lack of connectivity to metro stations makes metro passengers face a constant challenge. Connections from the origin to the metro station (access trip) and from the metro station to the destination (egress trip) are required. The trips for metro access and egress, which are the key components of metro travel and significantly affect the popularization of the metro system, can be multimodal, e.g., walking, bike-sharing, bus, ridesourcing, and taxi [5–7]. Due to zero emissions, flexibility, and low cost, walking and bicycling are suggested as friendly feeder modes to access/egress metro system [8]. But they are only suitable for short trips because of physical or mobility restrictions. When the distance of access/egress trip is long, taxi is more advantageous due to the efficient and convenient characteristics [9, 10]. Wang et al. also demonstrated that in the peripheral areas of the city where the distance to access/egress metro station was too long and bus service was less robust, bikes and taxis occupy higher proportions as the feeding modes [11]. Li et al. found that people living in the suburbs took taxis to the nearest subway station to maximize travel efficiency and cost-effectiveness [10].

Extensive studies have analyzed the bike-metro integrated use and studied the relationship between built environment and integrated bike-metro usage [12–15]. However, studies focusing on taxi-metro integrated use are scarce. Most rely on subjective surveys, which are limited by the spatial and temporal scales, and alternatively, OD data are most frequently used in mode choice analysis [16]. It has barely been discussed how the feeder-process-related (feeder-related) built environment impacts the integrated taxi-metro use. The relationship between feeder-related built environment and taxi-metro integrated use will contribute to optimizing urban transport structures and developing tailored land-use interventions to improve transit accessibility.

To address the above gaps, this paper explores the relationship between feeder-related built environment and taxi-metro integrated use in Lanzhou, China, where the utilization rate of dock-less bike-sharing is not popular due to the climate and road network. The main contributions of this study are summarized as follows: (a) calculating the transfer distance to delimit the catchment area; (b) comparing the characteristics of taxi-metro integrated use in different space-time environments; (c) employing the negative binomial regressions (NBL) to investigate the contributory role of feeder-related built environment in taxi-metro integrated use.

The remainder of this paper is organized as follows. Section 2 summarizes the related work. Section 3 describes the study data, integrated usage measurement, catchment area delineation, and method. Section 4 analyzes the spatial and temporal variations of taxi-metro integrated usage and discusses findings. Section 5 summarizes conclusions and policy implications, along with the limitations of this study and future research directions.

2. Literature Review

Built environment is an innate driver of travel needs [17–19]. Existing studies have explored the impact of built environment factors on travel demand in different modes (i.e., buses, metro systems, taxis, bicycles), presenting the differences among different travel modes [20, 21]. Understanding the relationship between built environment and travel patterns can contribute to the optimization of transportation infrastructure and future urban planning. This paper scrutinizes the feeder-related built environment impacts on taxi-metro integrated use, and the review is summarized as follows: (1) the feeder mode for metro access/egress; (2) the relationship between taxi use and built environment; (3) taxi-metro integrated use and its relationship with the built environment.

2.1. The Feeder Mode for Metro Access/Egress. As described in the introduction, the trip for metro access and egress (refers to taxi-metro integrated use) bridges the first-and-last-mile gaps. The feeder mode choice for metro access and egress is also affected by the characteristics of travel [5, 22]. Walking, bicycling, and bus are the most common feeding mode for metro access and egress [8, 23, 24]. Walking is considered as the most important way to feed the metro. The upper limits of walking distance for passengers are different between different metro stations with the range of 800 m–1200 m [25–27]. Pedestrians can only withstand no more than 10 minutes of walking into the transit [28]. Therefore, due to physical or mobility limitations, walking as a feeder mode may only be suitable for short trip.

Similarly, bike sharing is popular in many contexts and has many advantages, such as flexibility and easy pick-up and drop-off [29]. Extensive studies have studied bike-sharing as a feeder mode for metro transit [5, 10, 12–15, 24, 30]. These studies found that travel distance was the most important factor influencing commute rates between metro stations and home or workplace by bicycle, and the travel distance was roughly in the range of 500 m to 3000 m [31–33]. Chen et al. found that more than half of metro users preferred to use bicycle transfer services. Those passengers travel mainly for time-insensitive purposes, such as shopping and visiting friends [30]. Lee et al. and Zhao et al. found that bicycling may be more suitable for no time-intensive and short trips less than 3 km [34, 35]. However, the implementation of shared bicycles in some cities is relatively unsatisfactory due to the poor accessibility of the docking stations [36, 37]. Other travel modes such as bus, car, and taxi, which devote to a portion of feeder trips for metro access and egress, are also important [5, 16, 38, 39]. But predefined routes and fixed schedules constrain bus systems.

2.2. The Relationship between Built Environment and Taxi Use. Taxi is an important part of the urban transportation system, and the use is significantly affected by urban built environment. The urban built environment is the man-made environment of human activities and usually refers to the spatial environment formed by the interaction of various factors such as land use, transportation infrastructure, and urban design [40]. Built environment factors are often defined by such density of different types of land use, diversity (such as land-use mix), and design (such as road density) in past studies [41].

Many studies have been conducted to explore the relationship between taxi activities and built environment. Previous studies have shown that there is an intrinsic relationship between built environment factors and temporal patterns of taxi pick-up and drop-off dynamics [42]. For instance, Liu et al. found that the built environment, with high degrees of mixed land use, dense road junctions, and high percentages of residential, commercial area, had higher taxi demand, while in areas with more bus stops, the taxi demand was low [43]. Based on the data from 24 different regions in the United States, Sabouri analyzed how built-environment attributes affected Uber demand, revealing that demand was negatively correlated with intersection density and destination accessibility [44]. Since taxi demand is easily affected by other public transportation modes, some studies have also included transportation accessibility as an element of the built environment to explore the relationship between alternative modes of transportation [45]. For example, Yang et al. analyzed GPS dataset of NYC taxis and found that bus entry times were positively correlated with taxi demand [46].

2.3. Taxi-Metro Integrated Use and Its Relationship with Built Environment. With the facts mentioned above, the large volume of taxi GPS data has attracted more researchers to study the patterns and influencing factors of taxi activities. But only a few studies investigated taxi-metro integrated use [16, 47–49]. Ni and Chen found dockless shared bikes and taxis were the main feeder modes for metro access/egress due to high flexibility and accessibility and compared the temporal-spatial distribution of two modes as feeder mode, suggesting people living in central areas with high housing prices and well-developed arterial roads tending to take taxis during evening peak period [39]. Jiang et al. found that taxi, as a feeder mode for metro access, could increase the access distance to metro stations than walking and cycling, and the speed of metro-extending taxi trips was significantly higher than metro-complementing trip [49].

To promote synergistic multimodal transportation, many studies also explored the impacts of built environment factors on integrated bicycle-metro use. Metro stations near city centre, with higher land use mix, and more recreational and residential land, are more likely to generate more integrated bike-metro use [24, 50, 51]. Jin et al. investigated the nonlinear relationship between the built environment and metro-ridesourcing integration, showing higher integrated usage in the suburban areas [7]. Huang et al. revealed the relationship between multimodal transportation services and built environment [52]. However, how the feeder-related built environment impacts the taxi-metro integrated use remains unknown. There is also a lack of research on the transfer distances between taxi and metro to delimit catchment areas. This study aims to bridge these gaps and examine how feed-related built environment influences taxi-metro integrated use during peak hours.

3. Data and Methodology

3.1. Study Area and Data. Lanzhou, an important node city of the Silk Road Economic Belt located in Northwest China, is selected for this study. Lanzhou has a dry climate with four regular seasons. The daily temperature varies between 37°C in summer and −10°C in winter. Shared bikes are not well popularized in Lanzhou. The main public transport is conventional buses, taxis, and the metro. There is only one metro line with a length of 25.9 kilometer and 20 stations across the centre of Lanzhou, as shown in Figure 1. Meanwhile, Lanzhou has nearly 10798 taxis, and the average daily operating taxis are 9966, with the average daily use rate is 92.29% (https://jtw.lanzhou.gov.cn/art/2021/11/4/art_2652_1065192.html).

Spatial and vector data of urban roads, metro stations/lines, and bus facilities were extracted from Open Street Map (OSM). The data of POIs, including schools, hotels, business supermarkets, hospitals, and food related locations, were obtained from Baidu Maps through an open API interface publicly available (https://lbsyun.baidu.com/). In addition, the area of interest (AOI) was also obtained by API interface and processed by ArcGIS 10.2 to obtain land use data. The study area is divided into 1 km × 1 km grid cells to achieve fine-grained analyses.

Taxi trajectory data are obtained from urban transportation big data analysis and application laboratory of Lanzhou Jiaotong University. Seven-day taxi trajectory data (April 5–11, 2021) are collected including taxi ID, pick-up/drop-off time, pick-up/drop-off geolocations. According to some empirical studies, the features of taxi/ridesourcing-metro integrated use are relatively consistent over five weekdays [7, 15, 39].

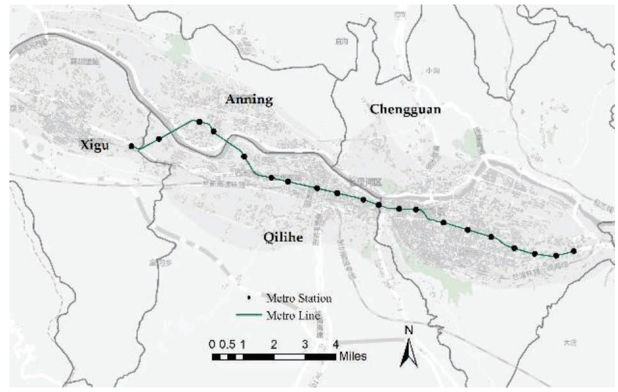


Figure 1: Study area.

3.2. Measuring the Variables

3.2.1. Measurement of Taxi-Metro Integrated Use. Many studies have defined the walking distance to metro stations, ranging from 400 to 800 m [48, 49, 53]. This study takes the acceptable walking distance (500 m [53, 54]) as the radial distance of metro stations to identify taxi-metro integrated use, as shown in Figure 2. A face-to-face questionnaire-based survey was conducted in Lanzhou from April to May 2021. We randomly selected 1000 taxi passengers whose origins or destinations were within 500 m of metro station entrance. Most respondents (>55%) indicated that their taxi trips were related to metro access or egress. At the same time, studies have proved that long access/egress distances (2-3 km [16]) and the presence of parking facilities are associated with higher probabilities of taking taxi over walking or cycling [55–58]. Some studies also have demonstrated that people are less willing to use nonmotorized modes for business and leisure travel [57, 59, 60]. As indicated by Yang et al., commuters may develop an intolerable attitude towards inaccurate bus frequency compared with crowded spaces, because inaccurate bus frequency often generated lateness uncertainty [38]. Poor feeder bus and bike-sharing system in Lanzhou comprise a major weakness. Therefore, considering the size of the sample, the accuracy of identifying taxi-metro integrated use is acceptable.

According to the following three steps, taxi-metro integrated use is identified.

Step 1. Identification of valid taxi trips

Firstly, duplicated and exceptional records from the same taxi are filtered. Then, taxi trips are extracted from taxi trajectory data. Finally, valid taxi trips are obtained by the following principles: (a) delete the trips that lack the coordinates of pick-up and drop-off locations or those outside the city boundary and (b) drop trips with unrealistic durations (i.e., trips lasting less than a minute, longer than 2 hours). The valid data during the metro service hours (6 : 00–23 : 00) are extracted for further analysis.

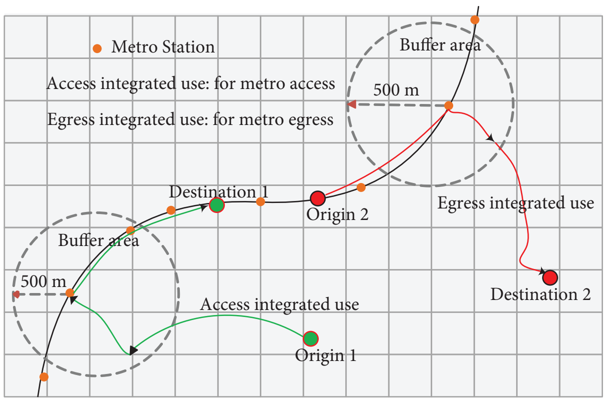


Figure 2: Access/egress integrated use.

Step 2. Identifying taxi-metro integrated use from the result of Step 1

Origins or destinations within 500 m of metro station entrance are used as transfer trips. This study merges all 500 m buffers around the station entrances into one buffer zone by ArcGIS10.2. Trips, whose origins or destinations are within the buffer zones of metro stations are identified. The trips can be divided into two types: (a) taxi-metro integrated use for metro access and (b) taxi-metro integrated use for metro egress. Based on the above method, taxi-metro integrated use for metro access and egress is obtained during morning and evening peak hours. As shown in Table 1, the average egress use and access use during peak hours on weekdays are around 44% and 35% more than peak hours on holidays and weekends. Meanwhile, the integrated use for metro access during morning peak hours (7–9 AM) is approximately 29% more than evening peak hours (5 : 30–7 : 30 PM), while the integrated use for metro egress during morning peak hours is approximately 31% less than evening peak hours. Meanwhile, measured by the sum of morning and evening peak hours, access use is larger than egress use.

As shown in Table 1, there is a difference in taxi-metro integrated use during morning peak and evening peak hours. As proposed by literature [32] and literature [51], the impact of feeder-related built environment features may vary by integration mode (access or egress) and time of day (morning or evening peak). Therefore, four NBL models are estimated with the following dependent variables: (a) taxi-metro integrated use for metro access during morning peak hours on weekdays, (b) taxi-metro integrated use for metro access during evening peak hours on weekdays, (c) taxi-metro integrated use for metro egress during morning peak hours on weekdays, and (d) taxi-metro integrated use for metro egress during evening peak hours on weekdays.

3.2.2. Catchment Area Delineation. For measuring the dependent and independent variables, the catchment area of metro stations needs to be defined. Its spatial boundary is determined by the transfer distance. In transportation studies, the transfer distance covering most metro passenger trips is regarded as the 85^{th} percentile of the cumulative distribution of access/egress distance [27]. In relevant studies, the transfer distance is widely used as metro station's search radius to delineate catchment area, which is also employed in this paper.

Table 1: Taxi-metro use for metro access and egress during peak hours.

Date	Access use		Egress use	
	AM peak	PM peak	AM peak	PM peak
Weekday:				
Tuesday (April 6)	3710	2603	2874	3578
Wednesday (April 7)	3824	2681	2831	3521
Thursday (April 8)	3760	2821	2392	3626
Friday (April 9)	3982	3120	2773	3501
Average	**3805**	**2806**	**2717**	**3558**
Holiday/weekend:				
Monday (April 5)	2318	2368	1383	2982
Saturday (April 10)	3028	2154	1870	2536
Sunday (April 11)	2544	2268	1500	2865
Average	**2630**	**2263**	**1569**	**2794**

Note. April 5th is Qingming festival. AM peak refers to morning peak hours, and PM peak refers to evening peak hours.

At the earliest, Lee et al. used quadratic regression and cubic regression to obtain the 85th percentile values [34]:

$$y = \alpha_0 + \alpha_1 x_1 + \alpha_2 x_1^2, \qquad (1)$$
$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_1^2 + \beta_3 x_1^3,$$

where y is the cumulative percent, and x_1 is the access distance, while $\alpha_i (i = 0, 1, 2)$ and $\beta_j (j = 0, 1, 2, 3)$ are the coefficients for quadratic regression and cubic regression, respectively.

To delimit the catchment area, this paper develops the quadratic regression model to explain taxi-metro integrated use distribution. As presented in Table 2, all models are statistically significant. Table 2 shows that the transfer distance is 3847 m/3796 m and 3830 m/3957 m for metro access/egress trips at morning and evening peak hours on weekdays. There are few variances of transfer distance for taxi-metro integrated use between weekdays and weekends. Thus, we take 3800 m as the search radius of the metro station's catchment area.

3.2.3. Variables. Table 3 shows the summary statistics of the dependent and independent variables. As formerly mentioned, the dependent variables include access use (integrated use for metro access) and egress use (integrated use for metro egress) at morning and evening peak hours, measured by the counts of the taxi-metro integrated use within each grid in the metro station's catchment area.

The independent variables used in the study are the feeder-related environment variables. The feeder-related (or feeder-process-related) built environment, proposed by literature [32], is related to origin/destination, transfer point of the station, and route to/from the station. Accordingly, taxi-metro integrated use includes five elements: people, metro, taxi, route, and urban space. The analytical framework of the feeder-related built environment for taxi-metro integrated use is shown in Figure 3. The independent

Table 2: Regression results of transfer distance of access and egress use.

Variable	Regression model	R^2	Sig	Transfer distance
Weekday:				
Access				
AM peak	$y = -0.0054 + 2.777 \times 10^{-4}x_1 - 1.392 \times 10^{-8}x_1^2$	0.997	0.000	3847
PM peak	$y = -0.0066 + 2.782 \times 10^{-4}x_1 - 1.389 \times 10^{-8}x_1^2$	0.998	0.000	3830
Egress				
AM peak	$y = 0.0018 + 2.751 \times 10^{-4}x_2 - 1.365 \times 10^{-8}x_2^2$	0.997	0.000	3796
PM peak	$y = -0.03 + 2.804 \times 10^{-4}x_2 - 1.385 \times 10^{-8}x_2^2$	0.997	0.000	3957
Holiday/weekend:				
Access				
AM peak	$y = -0.0472 + 2.849 \times 10^{-4}x_1 - 1.418 \times 10^{-8}x_1^2$	0.998	0.000	3910
PM peak	$y = -0.0026 + 2.774 \times 10^{-4}x_1 - 1.403 \times 10^{-8}x_1^2$	0.999	0.000	3775
Egress				
AM peak	$y = -0.066 + 3.008 \times 10^{-4}x_2 - 1.566 \times 10^{-8}x_2^2$	0.998	0.000	3794
PM peak	$y = 2.545 \times 10^{-4}x_2 - 1.132 \times 10^{-8}x_2^2$	0.998	0.000	4080

Table 3: Variable description and summary statistics.

Variables	Description	Min	Max	Mean	S.D.
Dependent variables					
Access use (AM peak)	Integrated use for metro access during the AM peak on weekdays	0	521	40.604	62.849
Access use (PM peak)	Integrated use for metro access during the PM peak on weekdays	0	364	31.022	47.775
Egress use (AM peak)	Integrated use for metro egress during the AM peak on weekdays	0	393	31.483	51.274
Egress use (PM peak)	Integrated use for metro egress during the PM peak on weekdays	0	404	39.135	54.606
Independent variables					
POIs	Number of POIs	0	77	6.114	13.278
Land use mix	Mixture entropy of nine land-use patterns	0	0.444	0.183	0.108
Percent residential	Proportion of residential land (%)	0	0.946	0.209	0.212
Percent commercial	Proportion of commercial land (%)	0	0.389	0.027	0.058
Percent others	Proportion of other use lands (%)	0	0.568	0.036	0.089
Road density	Road length ((m)/km^2)	0	25.416	9.298	5.296
Bus stop	Number of bus stops	0	115	15.163	20.650
Bus line density	The bus line length ((m)/km^2)	0	86.416	10.290	14.046

variables used in this study are selected based on previous studies [13, 17–19, 32, 39, 61] and include land use and transport facilities in this paper.

Subject to local data availability, the variables related to transport facilities include bus and road services. According to the current land use situation in Lanzhou, the proportion of commercial, residential, and other (vacant or green space) land use patterns within each grid in the metro station's catchment area is measured. POIs variables include the number of food-related locations, schools, hotels, business supermarkets, and hospitals within each grid in the metro station's catchment area.

The mixed land use is calculated by the entropy index as follows [52]:

$$E_j = -\frac{\sum_{ij} p_{ij} \ln\left(p_{ij}\right)}{\ln\left(k_j\right)}, \quad (2)$$

where p_{ij} is percent of land use i (commercial, residential, or others) in grid cell j, and k is the number of the land use types in grid cell j.

3.3. Models. To assess the effect of feeder-related build environment on taxi-metro integrated use, the dependent variable is the number of access or egress trips within each grid in the metro station's catchment area, which is non-negative integer. Poisson regression and NBL models are well-known for analyzing count data. However, if over-dispersion occurs, the latter is fitted to handle a long-tailed distribution and is preferable to the former because it does not constrain the variance to be equal to the mean [62]. Moreover, the NBL model has been widely used in travel behavior research [12].

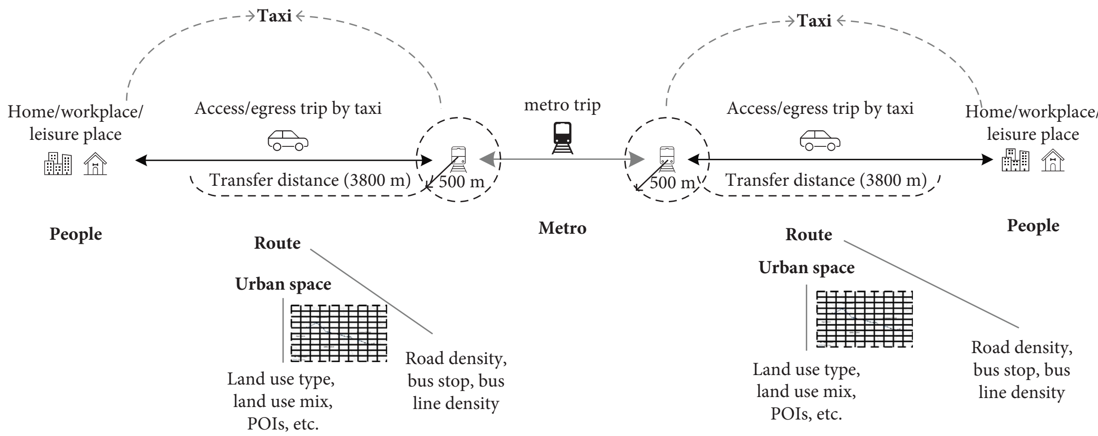


FIGURE 3: The feeder-related built environment for taxi-metro integrated use.

In this study, the dependent variables, taxi-metro integrated use for metro access/egress, are count data and have a substantial proportion of zeros. Therefore, we also apply the NBL regression model. The model can be expressed as follows [12, 62]:

$$\Pr\left(Y_i = k \,\middle|\, X_1, X_2, \cdots, X_n\right) = \frac{\Gamma(k + (1/\alpha))}{\Gamma(k+1)\Gamma(1/\alpha)}\left(\frac{(1/\alpha)}{(1/\alpha)+\lambda}\right)^{(1/\alpha)}\left(\frac{\lambda}{(1/\alpha)+\lambda}\right)^{y_i}, \quad y_i = 0, 1, 2, 3\cdots,$$
$$\lambda = E(Y_i) = \exp\left(\beta_0 + \beta_1 X_1 + \beta_2 X_2 + \cdots + \beta_n X_n + \varepsilon\right), \quad n = 1, 2, 3, \cdots, n, \tag{3}$$

where Y_i is the dependent variable representing the access or egress usage, and its value is count data ($k \in \{0, 1, 2, 3, 4\cdots\}$). $X_1, X_2, \cdots X_n$ are the independent variables representing the characteristics of the feeder-related built environment. Given independent variables $X_1, X_2, \cdots X_n$, $\Pr(Y_i = k)$ is the probability that the count number of taxi-metro integrated use for access or egress equals k. $\exp(\varepsilon)$ has a gamma (Γ) distribution with mean 1, and variance $\alpha (\alpha \geq 0)$ is the dispersion parameter. The variance is provided in equation (4), allowing for overdispersion:

$$\mathrm{Var}(Y_i) = \lambda + \alpha\lambda^2. \tag{4}$$

In the regression models, multicollinearity should be avoided. The level of multicollinearity is measured by variance inflation factor (VIF). In general, VIF > 10 indicates high multicollinearity, which should be dropped in the model (i.e., bus line density in this paper). Otherwise, low multicollinearity is acceptable [51].

4. Results and Discussion

4.1. Spatial and Temporal Variations of Access and Egress Use. The temporal patterns of daily taxi-metro integrated use for metro access or egress are presented in Figure 4. Taxi-metro integrated use has obvious morning peaks and evening peaks on weekdays, which indicates that taxi-metro integrated use plays an important role in daily commuting travel. While it is significantly different from peak hours on weekends, people have the lowest taxi demand to connect their origin/destination and metro stations during peak hours on weekends or at holiday. One possible explanation for this phenomenon is that trip purpose associated with taxi-metro integrated use differs between weekdays and weekends [18]. For instance, for time-sensitive weekday work trips, taxi-metro integrated use may be more reliable for commuters than other integrated use (i.e., bike-metro, bus-metro integrated use), while for trips with other purpose on weeke nds, travel utility of taxi-metro integrated use may be different.

Similar to the metro-integrated ridesourcing usage [7], both the morning peak and evening peak hours for access use are earlier than those for egress usage. The egress use has a 60-minute delay of access use during evening peak hours, while there is a 30-minute delay during morning peak hours on weekdays. Among taxi-metro integrated use during peak hours, the morning peak access use and the evening peak egress use are the highest as shown in Table 1, indicating that more taxi demand for commuting trips are used to connect metro stations and residential areas. This is in line with the results of the literature [7]. In addition, the morning peak integrated use is higher than that evening peak integrated use during weekdays. This may be because people are more time-constrained on weekday mornings and are more likely to use taxi as a feeder mode for the metro. However, it is just the opposite on weekends and holidays. One possible explanation for this is that people tend to choose more comfortable taxi service to metro stations and their destinations after their leisure time on weekends (see Table 1 and

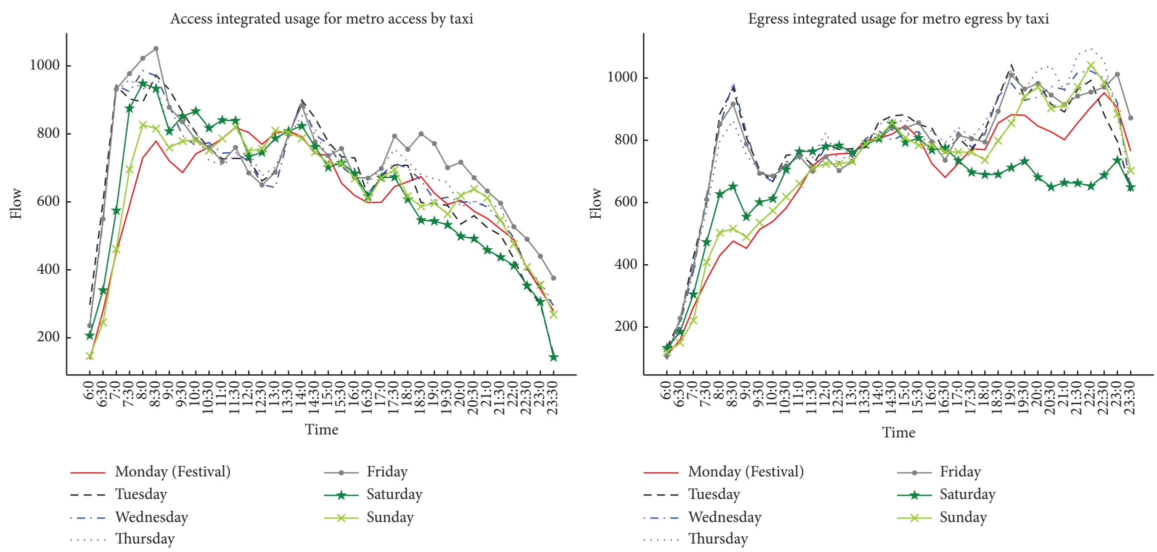


Figure 4: Time-varying features of taxi-metro integrated use for metro access/egress.

Figure 4). The non-negligible peak of egress usage after 21 : 00 further confirms this view (see Table 1 and Figure 4).

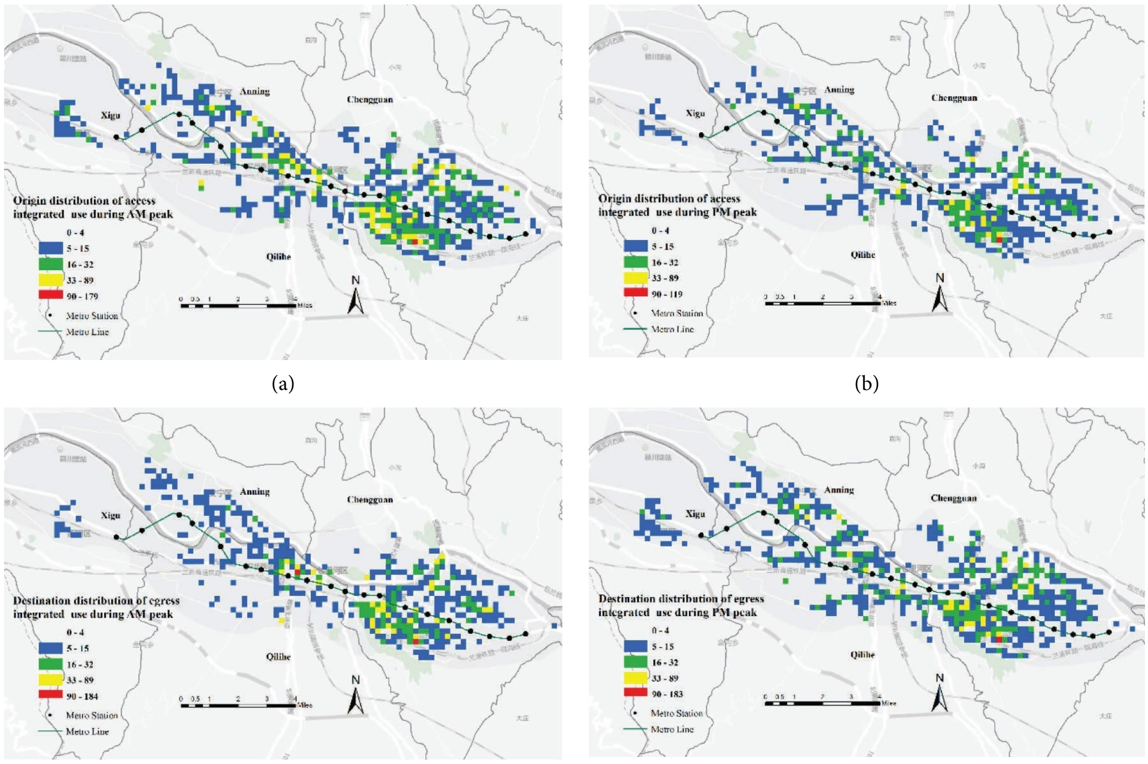
As shown in Figure 5, the origins of access trips and destinations of egress trips are mapped into grids, whose spatial distribution are different, revealing a higher degree of spatial heterogeneity. The distribution reveals that people who live in the east of Chengguan district and west of Anning district covered by few metro stations are less likely to use taxi as feeder mode to access/egress metro. In contrast, the area where residential communities gather (e.g., southeast of Chengguan district) attracts much integrated use. It is worth noting that a large amount of integrated usage mainly occurs in Chengguan and Qilihe districts of the four districts. This may have relation to the density of metro stations, the high proportion of commercial land use, and the large number of POI in these two areas. Due to the development of universities and business, the integrated usage has been gradually improved in the Anning district.

4.2. Modeling Results. After excluding the multicollinearity of independent variables, all variables are included in the NBL model to explore how the feeder-related built environment influence on taxi-metro integrated use during weekday peak hours. The modeling results are shown in Table 4, which demonstrates the relationship between the feeder-related built environment and taxi-metro integrated use. The overdispersion parameters α of the four models are significantly different from 0. This illustrates that our data are overdispersed and the NBL model can be applied.

Home and workplace are related to commuting, making it essential that taxi becomes a feeder mode during peak hours. As shown in Table 4, the POIs within the metro station's catchment area positively influence egress integrated usage during morning peak hours on weekdays while the POIs have no significant effect on the integrated taxi-metro use for metro egress during evening peak hours and integrated taxi-metro use for metro access, which is in line with the literature [63]. There is also a positive correlation between egress integrated use and mixed land use during peak hours, and more taxi-metro integrated use is observed when the mixed land use is higher, especially for the evening peak egress usage. This can be explained that higher mixed land use triggers more activity types than just commuting trips. However, the mixed land use does not have a significant impact on morning peak access usage. This is possibly because that origins of commuting trips in an area with higher mixed land use, where contains intermingled activities such as offices, shops, and restaurants, induce the availability of destinations to which residents can walk or take bus.

Moreover, the results demonstrate that it is favorable of taxi-metro integrated use during evening peak hours for residential land use. Still, it only has a positive effect on access integrated use during morning peak due to the following reasons: one is that people are more willing to access the metro station by taxi for commuting or going to school on time during the morning peak; the other is that the metro line of Lanzhou is located in the city centre with heavy traffic during peak hours, so people often use taxi-metro or metro-taxi to avoid congestion during the evening peak.

Table 4 also shows that the higher ratio of commercial area in metro catchment areas reduces the integrated taxi-metro use for metro egress during morning peak. This suggests that people who use the metro are mainly commuters during morning peak. Therefore, after leaving the metro station, few people take taxi to go shopping and conduct entertainment activities in the surrounding area, reducing the short trips between metro stations and commercial streets and thus inhibiting integrated taxi-metro use. Compared to commercial and other land use, mixed land use and increased residential area within metro catchment areas could lead to more short trips



(a) (b) (c) (d)

Figure 5: Spatial distributions of taxi-metro integrated trips at AM and PM peaks: (a) integrated taxi-metro use for access at AM peak, (b) integrated taxi-metro use for access at PM peak, (c) integrated taxi-metro use for egress at AM peak, and (d) integrated taxi-metro use for egress at PM peak.

Table 4: Modeling results of NBL models.

Variable	AM peak				PM peak			
	Access usage		Egress usage		Access usage		Egress usage	
	Coefficients	P	Coefficients	P	Coefficients	P	Coefficients	P
POIs	0.319	0.731	0.221***	0.003	0.082	0.300	0.079	0.329
Land use mix	0.922	0.315	2.809***	0.000	2.369***	0.004	2.061**	0.013
Residential	1.854***	0.004	0.733	0.155	1.979***	0.000	2.226***	0.000
Commercial	−0.889	0.542	−2.203*	0.083	−1.607	0.188	−1.047	0.407
Others	−1.119	0.343	−1.584	0.087	0.162	0.876	−0.160	0.871
Bus stop	0.859***	0.000	0.664***	0.000	0.898***	0.000	0.645***	0.000
Road density	0.409*	0.073	0.635***	0.001	0.401*	0.055	0.525**	0.010
Constant	−0.399	0.338	−1.001***	0.006	−1.147***	0.004	0.439	0.227
α	0.994***	0.000	0.593***	0.000	0.663***	0.000	0.741***	0.000
Log-likelihood	−851.54		−794.74		−773.02		−875.09	
Pseudo R^2	0.120		0.164		0.162		0.130	

Note. $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$.

between home and workplace, thereby facilitating integrated taxi-metro use.

The transportation-related built environment plays a critical role in metro passengers to select taxis as a feeder mode. Among the included public transportation facility factors, road network density is a good indicator of the quality of urban transportation infrastructure. The density of road network has a positive effect on the passengers' preference to use taxis as a feeder mode to access/egress metro. The developed road network leads to more taxi-metro integrated use, especially during morning peak period. One possible explanation for this finding might is that people are primarily concerned with the time reliability of feeder mode during morning peak hours because they are not willing to be late for school or work while well-developed road network will lead to higher exposure to flexible taxi on the road and less waiting time. This result is partially consistent with finding reported in previous studies [39]. Concerning bus services, the number of bus stops within catchment area of a metro station positively affects the use of integrated taxi-metro. This is due to the increase of bus stops within metro catchment areas, which increases passenger waiting time. Greater availability of bus stops makes more commuters to get to their destinations by bus, which also cause crowdedness [15]. These negative effects motivate some bus-metro integrated users to become taxi-metro integrated users.

5. Conclusion

Connections from trip origins to the metro system (access trip) and from the metro system to the trip destinations (egress trip) are critical components of a commuter's entire trip [38]. This paper mainly focuses on taxi-metro integrated use and explores the impact of the feeder-related built environment on taxi-metro integrated use during peak hours on weekdays. By focusing on Lanzhou, China, this study identifies 12886 integrated trips, with 6275 egress trips and 6611 access trips during peak hours on weekdays (April 6–9, 2021). 9256 integrated trips are identified, with 4363 egress trips and 4893 access trips during peak hours on weekends. People have a higher demand for taxi-metro integrated use on weekdays than on weekends. Moreover, People also tend to take taxi for metro-access than metro-egress, which is in line with the literature [7]. On weekdays, there are two peaks for integrated taxi-metro use, and the egress trips give 30-minute and 60-minute lags in the access trips during morning and evening peaks, respectively. To determine the transfer distance, a quadratic regression model is established to calculate the transfer distance of access and egress trips. The average egress distance threshold is slightly longer than the average access distance threshold.

In view of land use characteristics, higher proportion of commercial and other (vacant, green space) land use at the destination reduces the probability of taking taxi for egress purpose at morning peak. On the origin side, higher proportion of residential land use seems to encourage the use of taxi for metro access during peak hours and for metro egress during evening peak. Higher mixed land use would lead to higher taxi-metro integrated use. The transportation-related built environment plays a significant role in metro passengers to take taxi as a feeder mode. The road network density has a positive influence on integrated taxi-metro use. The increase of public bus stops will lead to long waiting time and crowdedness. Thus, these negative effects motivate some bus-metro integration users to become taxi-metro integration users.

Based on the above findings, some important policy and operational implications could involve the following. First, the transfer distances for metro access and egress trips by taxi range from 3.7 to 4.0 km during peak hours, which is not very long compared with the transfer distance of bike-metro integrated use (shorter than 3 km [27]). Therefore, it has great potential to shift taxi-metro integrated use to bike-metro/bus-metro integrated use. Second, understanding the relationship between feeder-built environment and taxi-metro integrated usage can provide guidance for taxi drivers to pick up passengers quickly during peak hours. Third, land use patterns have different effects on the use of taxi for access and egress purpose, and optimal policies and decisions should differ across areas with different built environment attributes. Considering this spatial heterogeneity, traffic management and urban planning department can adapt strategies and programs at the local scale to improve transit accessibility. For example, since residential land positively impacts taxi-metro integrated use, traffic managers may consider community buses for metro access and egress during peak hours.

This study has some limitations. First, taxi and metro are separate and independent systems in Lanzhou, and the observed data between taxi and metro cannot be directly connected. Although the procedure to identify taxi-metro integrated use in this paper has also been adopted by exiting related research [7, 15], only approximate results can be obtained. Second, only one week taxi trip data were analyzed. In future research, longer time range data are needed to further examine the regularity of taxi-metro integrated use. Third, the selected city in this study is Lanzhou, a city with relatively simple land use types and underdeveloped urban public transport system; therefore, the conclusions obtained in this paper may not be applicable to larger cities. Additionally, demographic and socioeconomic attributes are significantly associated with transit affordability [64, 65]. We look forward to getting these data sources for more in-depth research. Nonetheless, our findings will help transport planners to optimize urban mobility structures and develop tailored land-use interventions to improve transit accessibility and promote the sustainable multimodal travel.

Data Availability

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Authors' Contributions

Qixiang chen and Bin lv conceptualized the study and developed the methodology. Binbin Hao collected and curated the land use data. Xianlin Li collected and curated the taxi data. Qixiang chen wrote the Python code for this paper. Qixiang chen and Bin lv prepared and wrote the original draft. Binbin Hao and Xianlin Li edited the manuscript. Bin Lv supervised the study. All the authors have read and agreed to the published version of the manuscript.

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