Influence of built environment on transit trips with different purposes: A case study of the central urban area in Jinan

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Abstract: A well-designed built environment promotes transit use, public health, and quality of life. This study conducted an empirical analysis of the central urban area of Jinan, considering four trip purposes: commuting, shopping, schooling, and leisure. The analysis employed the "5Ds" framework of built environment indicators in combination with binary and multinomial logistic regression models. Findings revealed substantial variation in how built environment factors shape different types of transit trips. Specifically, shopping trips were strongly associated with multifunctional commercial centers featuring high metro accessibility; commuting displayed a "U-shaped" dual-center pattern, with flows concentrated in both the urban core and suburban industrial parks; leisure travel often originated in mixed-use residential neighborhoods and extended toward open spaces; and school trips were influenced mainly by regular bus routes connecting central residential districts to suburban schools. Based on these insights, the study recommends implementing a purpose-oriented TOD model. Key priorities include strengthening the polycentric spatial structure, improving the integration of blue-green infrastructure with the public transit system, and aligning school district planning more closely with transit networks. These strategies provide theoretical guidance and practical pathways to advance "public transit priority" policies and sustainable mobility planning in Jinan and other comparable urban contexts.

1. Introduction

Urban public transit constitutes a vital component of modern transportation systems, with its level of development directly influencing urban efficiency, residents' quality of life, and the realization of sustainable development goals. Around the world, prioritizing public transit has become a central strategy for megacities seeking sustainable growth. Global "transit metropolises" such as Tokyo, Paris, London, Singapore, and Hong Kong, China, demonstrate how well-designed systems support city operations. In Tokyo, rail transit accounts for approximately 86% of passenger trips, with a combined metro and railway network extending over 3,000 kilometers, making it one of the most extensive and dense rail systems globally. Hong Kong, China, offers another striking example: nearly 90% of all trips are made by public transit, thanks to the integration of a "public transit priority" policy with a highly developed rail network. Remarkably, it manages a traffic volume comparable to Shanghai's, despite having only one-third of Shanghai's total road mileage. The roots of the "public transit priority" concept can be traced back to Paris in the 1970s, where the introduction of more than 480 dedicated bus lanes improved transit speeds by 20-30% and reduced vehicle emissions by 20-40%.

China's urban public transit system has progressed through three key stages: from a weak foundation, to rapid scale expansion, and finally to improvements in quality. In the early years of the People's Republic of China, only 2,292 buses were in operation nationwide, concentrated mostly in major cities. By the onset of the reform and opening-up era, the total number of buses had increased but still remained under 30,000, serving an annual passenger volume of 13.2 billion trips. At that time, bicycles continued to dominate as the primary travel mode. Significant growth occurred following the market-oriented reforms introduced in 1985 and the adoption of the concession system in the 1990s. Nevertheless, with China's accelerating socio-economic development and rapid urban expansion, transport-related challenges became increasingly acute. Public transit subsequently emerged as a crucial solution for mitigating traffic congestion, enhancing road network efficiency, and reducing air pollution, owing to its low road space consumption, high passenger-carrying capacity, and relatively low emissions. In 2021, the government issued a national plan for the 14th Five-Year Plan period, which highlighted the implementation of a "public transit priority" strategy and promoted the development of national-level transit metropolises.[1] This policy direction has since gained broad consensus in China's urban development agenda. Most recently, on December 1, 2024, the Regulation on Urban Public Transport came into force. The regulation formally designated municipal governments as the primary authorities responsible for public transit development, while underscoring both the

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public welfare nature of transit services and the governmental obligation to provide financial support.

Before advancing a "public transit priority" strategy, it is essential to first understand residents' travel demands and identify the factors influencing their choice of transit. This step is critical for ensuring both the effective implementation of the policy and the realization of its intended outcomes. Research has shown that transit travel behavior varies significantly across population groups and trip purposes. Some scholars argue that public transit plays a particularly important role for vulnerable urban populations.[2] For instance, older adults rely heavily on public transit due to physical constraints and restrictions on driving; adolescents frequently use it for school attendance and social interaction; and low-income groups often prefer it because of its affordability. From a travel-purpose perspective, the activity-based trip chain framework has gained growing attention, as time-geography perspectives emphasize that travel is derived from underlying activities.[3] Different trip purposes, such as commuting (work, education), shopping (retail, healthcare), and leisure (recreation, visiting friends), exhibit notable variations in spatiotemporal patterns, distance sensitivity, and service requirements. Recognizing these distinctions is a prerequisite for the precise optimization of public transit service configurations.

Residents' decisions regarding transit use are shaped by a wide range of interrelated factors. Existing research on the determinants of travel behavior generally highlights three major dimensions: socio-economic characteristics, policy interventions, and the built environment.[4] Studies on socio-economic attributes examine the effects of variables such as age, gender, income, occupation, and household composition. For example, Páez et al. reported that age negatively influences mobility among the elderly, reducing both trip frequency and distance. They also found gendered differences, with older women typically recording higher travel frequencies than their male counterparts.[5] Abraham J. investigated the interaction of sex and age with commuting patterns in working households, noting that one member's workplace location often shapes the commuting behavior of other family members.[6] Similarly, Gadepalli R. emphasized that mode choice is strongly affected by sex, income level, and travel time.[7] Policy factors, on the other hand, function as external regulatory mechanisms that directly influence travel cost and convenience through economic and administrative measures. Research in this area has primarily focused on pricing and restrictions, including congestion charges, parking fees, public transit fares, and traffic limitation policies, and their impacts on mode choice. Fan Aihua argued that flexible policies can effectively encourage residents to adopt greener travel modes.[8] Wang Lijing demonstrated a negative correlation between transit ridership and fares, with fare increases exerting a stronger deterrent effect on short-distance trips.[9] Beyond these direct levers, travel choices are also shaped by perceptions, attitudes, and other subtle incentives or barriers. Hu Song et al. found that positive perceptions of public transit, particularly regarding safety, convenience, and overall satisfaction, significantly strengthen the intention to use it.[10] In contrast, Shin E. and colleagues, examining suburban communities in Melbourne, Australia, concluded that residents' choices were less constrained by deficiencies in the transit system itself than by the additional fuel costs incurred for longer car trips.[11]

Beyond socio-economic and policy factors, the built environment, serving as the physical foundation of travel behavior, has attracted growing scholarly attention. Numerous studies have confirmed that built environment indicators significantly shape residents' decisions to use public transit. For example, Zhao Pengjun et al. demonstrated that areas with high land-use mix and convenient transfer services foster greater reliance on public transit and non-motorized modes. Moreover, differences in time efficiency mean that long-distance commuters are more inclined to travel by metro.[12] Xie Shuai observed contrasting effects of distance from the city center: commuting trips showed a positive correlation with transit use, whereas daily trips exhibited a negative relationship.[13] Similarly, Liu Kaili identified strong associations between the built environment and the transit travel frequency of older adults, particularly in relation to station density, accessibility, and land-use diversity.[14] Gao Yue'er reported that higher accessibility of transit stations in suburban areas increases the likelihood of residents opting for transit.[15] Shi Fei further emphasized that distance to the nearest metro station, the extent of network overlap, and the density of intersections and land-use mix all play decisive roles in promoting transit ridership.[16] Several studies have also focused on how built environment factors influence travel with specific purposes. Sun Bindong et al. found that residential areas characterized by greater population density, intersection density, and land-use diversity significantly increase the share of commuting trips made by public transit.[17] Guo Yan et al. argued that high residential density, road network density, and accessibility enhance connectivity and facilitate pedestrian-transit integration, thereby encouraging both active and public transit commuting.[18] Zhu Jing et al., studying Xi'an, revealed that workplace population density, building density, road network density, distance to the city center, and the number of available transit lines all contribute to shaping residents' commuting mode choice.[19] Focusing on adolescents, Liu Jixiang et al. demonstrated that the built environment around both home and school, especially distance to the urban core and intersection density, plays a critical role in determining whether students walk to school.[20]

In summary, most existing studies emphasize overall transit mode choice but often neglect variations across different travel purposes such as commuting, shopping, and leisure. Moreover, the impact of the built environment is not uniform and may differ considerably depending on the type of travel behavior. To address these gaps, this study focuses on the central built-up area of Jinan, Shandong. Using the "5Ds" framework of built environment indicators proposed by Ewing and Cervero,[21] the research identifies both the optimal measurement scales of the built environment and the key factors influencing transit mode share. A binary logistic regression model was applied to address the lack of a

quantitative basis for selecting measurement scales. Furthermore, the effects of built environment characteristics on transit trips were examined across four distinct travel purposes, commuting, shopping, schooling, and leisure. The findings provide a methodological reference for determining appropriate built environment scales in future studies and offer practical guidance for urban transport planning. They also support the advancement of "public transit priority" strategies in Jinan, contribute to the refinement of transit services, and supply a theoretical foundation for promoting sustainable transportation development in other comparable cities.

2. Study area, data and methods

2.1. Profile of the study area

Jinan, the capital of Shandong Province and widely known as the "City of Springs," serves as a major national comprehensive transport hub with a highly interconnected network system.[22] The city is currently shifting from the "Daming Lake era" to the "Yellow River era" under a new urban development strategy characterized by the principles of "Strengthening the East, Revitalizing the West, Beautifying the South, Initiating the North, and Optimizing the Center." This transformation places increasing demands on the transport system as the city undergoes spatial expansion and functional reorganization. However, large-scale underground rail transit development is limited by Jinan's distinctive linear urban form, as well as its complex and sensitive geological and hydrological conditions. With rapid urbanization, the city's permanent population reached 9.515 million by the end of 2024, according to the Jinan Bureau of Statistics, alongside a private vehicle ownership of approximately 4.121 million units. These trends have intensified challenges such as traffic congestion, air pollution, and resource depletion.[23] Consequently, the role of the ground-based public transit system has become increasingly critical within the city's passenger transport framework.

This study concentrates on Jinan's central urban area, which covers approximately 2,000 square kilometers (see Fig. 1). The transport network comprises three ring roads and 15 radial arterial and secondary roads, with a total road mileage of nearly 15,000 kilometers. Public transit services include 780 routes extending 16,529.2 kilometers in length and accommodating around 590 million passenger trips annually. The area is characterized by high population density, extensive mixed-use infrastructure, and well-developed transit services, while simultaneously experiencing a critical phase of urban restructuring and transport transformation. These features make it a particularly suitable case for empirically examining how built environment factors influence transit travel behaviors across different purposes, namely commuting, shopping, schooling, and leisure.

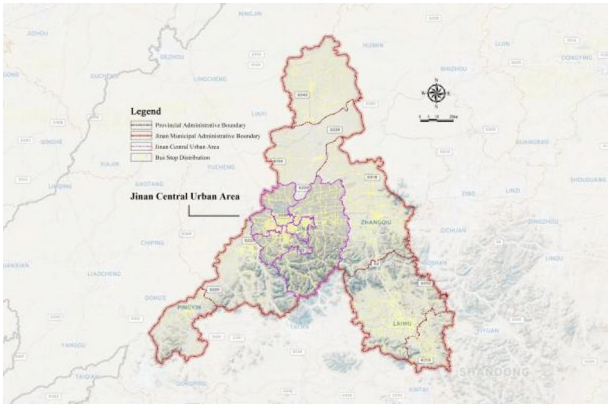

Fig. 1. Overview of Jinan central urban area.

2.2. Data source and processing

Data on transit travel behavior were obtained from the 2019 Jinan Travel Characteristics Survey (JNTCS 2019), which investigated the travel patterns of Jinan residents. To ensure representativeness, the survey was conducted in July 2019 by trained investigators using a probability proportional to size (PPS) sampling approach. A total of 44,084 adults from 698 residential communities within the central urban area were recruited.[24] Each participant provided detailed one-day travel diaries, including trip purpose, start and end times, origin, and destination. After pre-processing and removing outliers, 4,081 valid transit trip records were retained for analysis, covering four primary purposes: commuting, shopping, schooling, and leisure. Of these, commuting accounted for the largest share with 1,550 trips (38.0%), followed by leisure with 1,164 trips (28.5%), shopping with 900 trips (22.1%), and attending school with 467 trips (11.4%).

2.3. Variable indicator system

The built environment refers to the human-made surroundings created to support daily activities,[25] including large-scale urban environments.[26] In the context of urban planning, it is generally understood as the physical spaces where people live and work, such as buildings, streets, and open areas. These environments are characterized by both spatial extensiveness and local clustering. To evaluate the impact of the built environment on travel behavior, one of the most widely used frameworks is the 3Ds model proposed by Cervero,[27] which considers three dimensions: Density, Diversity, and Design. Ewing later extended this model into the 5Ds framework by adding destination accessibility (DA) and Distance to Transit (DT).[21] In this framework, Density and Diversity capture the distribution of activity destinations that satisfy residents' living needs; Design and DT serve as integrated indicators reflecting land-use patterns and features of the urban transport system; and DA functions as a locational measure describing spatial distribution characteristics in relation to the urban core. The variables selected for this study, along with their calculation methods, are presented in the Table 1 below.

Table 1. Summary of variable indicator system.

Indicator	Variable	Variable Explanation
Density	Road network density (Unit of measurement: km/km²)	Within an 800-metre buffer zone of a resident's departure or arrival point, the total length of the road network is divided by the buffer zone area.
Diversity	POI mix entropy	Within an 800-metre buffer zone around residents' departure or arrival points, calculate the proportion of each POI category and determine the mixed entropy value using the Shannon-Wiener index.
Design	POI Density (Unit of measurement: number/km²)	Within an 800-metre buffer zone around residents' departure or arrival points, the total number of POIs is divided by the buffer zone area.
	Intersection Density (Unit of measurement: number/km²)	Within an 800-metre buffer zone around residents' departure or arrival points, the total number of POIs is divided by the buffer zone area.
Distance to Transit	Bus Stop Distribution (Unit of measurement: number/km²)	Within an 800-metre buffer zone around residents' departure or arrival points, the total number of POIs is divided by the buffer zone area.
	Subway Station Distribution (Unit of measurement: number/km²)	Within an 800-metre buffer zone around residents' departure or arrival points, the total number of POIs is divided by the buffer zone area.
Destination Accessibility	Distance to CBD (Unit of measurement: km)	Distance from resident departure or arrival points points to Jinan Central Business District.

3. Data analysis and result

3.1. Binary logistic regression model specification

The dataset consisted of 4,081 valid transit trip records from Jinan, with the dependent variable defined as travel purpose across four categories. To ensure the robustness of the models and the reliability of results, 14 built environment variables underwent systematic pre-processing prior to analysis. Station density variables were transformed into binary "present/absent" indicators to address the common problem of zero inflation, thereby preventing model non-convergence caused by complete data separation. The remaining continuous independent variables were standardized using Z-scores, yielding a mean of 0 and a standard deviation of 1. This process eliminated dimensional differences and improved the comparability of model coefficients.

The primary analytical methods employed were binary logistic regression and multinomial logistic regression. All models satisfied collinearity diagnostics, with variance inflation factor (VIF) values below 5 for all variables (excluding structural collinearity arising from model specification). Given the exploratory nature of the study, a significance threshold of $p < 0.2$ was adopted: variables with $p < 0.1$ were considered statistically significant, while those with $0.1 \leq p < 0.2$ were treated as marginally significant and interpreted with caution.

3.2. Binary logistic regression analysis: influencing factors by travel purpose

Independent binary logistic regression models were developed for each of the four travel purposes to examine their underlying driving factors. The diagnostic outcomes (see Table 2) and principal findings (see Table 3) of these models are presented in the following sections.

Table 2. Diagnostics outcomes of binary logistic regression models for four travel purposes.

Travel purpose	Hosmer-Lemeshow test (p-value)	McFadden R^2	Likelihood ratio test (p-value)
Shopping	0.060	0.060	<0.001
Commuting	<0.001	0.029	<0.001
Leisure	0.004	0.043	<0.001
Schooling	0.193	0.014	<0.001

Table 3. Results of binary logistic regression models for four travel purposes.

Independent Variable	Shopping			Commuting			Leisure			Schooling		
	Regression Coefficient	Odds Ratio	P-value	Regression Coefficient	Odds Ratio	P-value	Regression Coefficient	Odds Ratio	P-value	Regression Coefficient	Odds Ratio	P-value
X1 Road network density at origin	—	—	—	—	—	—	-0.012**	0.989	0.029	—	—	—

X2 Road network density at destination	-0.016***	0.984	0.004	—	—	—	0.031***	1.031	0	-0.02***	0.98	0.007
X3 POI density at origin	-0.001***	0.999	0.003	0.001***	1.001	0	0.001*	1.001	0.097			
X4 POI density at destination	0.005***	1.005	0	-0.003***	0.997	0	-0.002***	0.998	0	0.001	1.001	0.109
X5 Intersections density at origin	0.001***	1.001	0.001	—	—	—	-0.001**	0.999	0.029	—	—	—
X6 Intersections density at destination	-0.001**	0.999	0.028	—	—	—	—	—	—	—	—	—
X7 POI mix entropy at origin	-0.409*	0.664	0.094	—	—	—	0.479**	1.614	0.046	0.432	1.541	0.187
X8 POI mix entropy at destination	1.345***	3.838	0	—	—	—	-0.458***	0.633	0.009			
X9 Presence/ Absence of subway station at origin	—	—	—	—	—	—	0.163	1.177	0.105	-0.279*	0.757	0.066
X10 Presence/ Absence of subway station at destination	0.783***	2.189	0	0.183*	1.201	0.057	-1.001***	0.368	0	-0.289*	0.749	0.063
X11 Bus stop density at origin	0.028*	1.029	0.098	-0.039***	0.962	0.007	0.022	1.022	0.166	—	—	—
X12 Bus stop density at destination	-0.094***	0.91	0	0.135***	1.144	0	-0.097***	0.908	0	—	—	—
X13 Distance from origin to CBD	-0.019**	0.981	0.036	0.036***	1.036	0	-0.017**	0.983	0.022	-0.021*	0.979	0.063
X14 Distance from destination to CBD	0.099***	1.104	0	-0.099***	0.906	0	—	—	—	0.036***	1.037	0.001
X15 Squared distance to CBD from destination	-0.002***	0.998	0.004	0.002***	1.002	0	—	—	—	—	—	—

Only variables with P<0.2 are displayed

Note: ***p < 0.0l, **p < 0.05, *p < 0.

3.2.1 Transit trip for shopping

The likelihood ratio test (LRT) yielded p < 0.001, confirming that the model is statistically significant. The Hosmer-Lemeshow test produced p = 0.06, indicating a good fit between the model's predictions and the observed data. The McFadden R-squared (McFadden R^2) was 0.060. The results can be interpreted as follows:

(1) Destination environment as the decisive factor. Destination characteristics play a critical role in shopping trips. Multi-functional space (X8, OR = 3.838) and the presence of a metro station (X10, OR = 2.189) emerged as the strongest motivating factors. This pattern clearly points to large commercial complexes or urban business

districts, where multi-functional spaces and well-developed public transit services are typically concentrated.

(2) Origin environment reflecting residential characteristics. Unlike multi-functional destinations, the origins of shopping trips tend to be single-functional areas (X7, OR = 0.653), which is consistent with the typical characteristics of residential neighborhoods.

(3) Distance exhibiting significant "inverted U-shaped" nonlinearity. The model produced a positive coefficient for X14 and a negative coefficient for X15, both highly significant. This demonstrates an inverted U-shaped relationship: as the distance from the central business district (CBD) increases, the likelihood of a destination being a shopping location first rises and then declines. The results suggest that the most attractive shopping destinations accessible by public transit are not concentrated in the city center or the distant suburbs, but rather in sub-centers or large commercial hubs located at intermediate distances and supported by metro access. This finding challenges the assumption of a simple linear distance effect.

3.2.2 Transit trip for commuting

The LRT yielded $p < 0.001$, confirming that the model is statistically significant. The McFadden R^2 was 0.029. However, a limitation should be noted: the model failed the Hosmer-Lemeshow test, with a p-value close to 0, indicating a systematic deviation between predicted probabilities and observed data. Despite this, the study's primary aim is to identify key influencing factors and their directions of influence. Accordingly, the variable relationships revealed by this model still provide valuable theoretical and practical insights. The results are interpreted as follows:

(1) Residence-workplace spatial features are significant for commuting trips. The distance of the origin from the CBD (X13, OR = 1.036) has a significant positive influence, indicating that the probability of commuting increases with greater distance from the central urban area. This reflects the typical commuting pattern of "suburban residence."

(2) Distance to destination shows a U-shaped nonlinearity. The regression coefficient for X14 is negative, while for X15 it is positive, both highly significant. This reveals a U-shaped relationship: as the distance of a destination from the CBD increases, the likelihood of it serving as a commute destination first decreases and then rises. This pattern suggests two dominant types of commuting destinations: traditional employment centers in the urban core and emerging industrial parks or sub-centers located in the outer suburbs.

(3) Influence of transport and supporting facilities. Commuting destinations are generally supported by stronger transport infrastructure. The presence of a metro station (X10, OR = 1.201) and higher public transit station density (X12, OR = 1.144) both significantly increase the probability of commuting. Interestingly, POI density (X4, OR = 0.997) is lower for commuting destinations, consistent with the single-functional nature of office districts and industrial parks, in contrast to the higher mixed-use density of commercial areas.

3.2.3 Transit trip for leisure

The LRT yielded $p < 0.001$, confirming the statistical significance of the model. The McFadden R^2 was 0.043. However, the model failed the Hosmer-Lemeshow test ($p = 0.004$), indicating a systematic deviation between predicted probabilities and observed data. Despite this limitation, the study focuses on identifying the key influencing factors and their directions of effect, which still provide meaningful theoretical and practical insights. The results are interpreted as follows:

(1) Leisure destinations exhibit "park green space" characteristics. Unlike shopping or commuting destinations, leisure destinations show distinctive environmental features, including single-function use (X8, OR = 0.633), absence of metro stations (X10, OR = 0.368), low public transit station density (X12, OR = 0.908), and low POI density (X4, OR = 0.998). These characteristics correspond to open urban spaces with simple functions, distant from major transport hubs and commercial centers, such as large parks, riverfront green belts, or scenic areas. This sharply contrasts with the heavy dependence on transport hubs and commercial centers observed in shopping and commuting trips.

(2) Origins of leisure trips reflect "vibrant central communities." Leisure trip origins are more likely to be multi-functional areas (X7, OR = 1.614) located close to the CBD (X13, OR = 0.983). This suggests that residents living in central urban areas with abundant living facilities are more inclined to use public transit for leisure activities.

(3) Road network and accessibility effects. The model indicates that leisure destinations tend to have denser road networks (X2, OR = 1.031), consistent with the fact that "park green spaces" are often integrated into built-up urban districts. By contrast, both the road network density (X1) and the number of intersections at the origin show negative correlations, suggesting that leisure trips by public transit are more common among residents of large "superblock-style" residential areas with relatively simple road layouts.

3.2.4 Transit trip for attending school

The LRT yielded $p < 0.001$, indicating that the model is statistically significant. The McFadden R^2 was 0.014. The Hosmer-Lemeshow test produced $p = 0.193$, suggesting a good fit between predicted probabilities and observed data. Among all four models, this was the best-fitting one. The results are interpreted as follows:

(1) School destinations exhibit "suburban campus" characteristics. Destinations for attending school (e.g., schools and university campuses) are typically located farther from the CBD (X14, OR = 1.037), in areas with lower road network density and limited metro access (X10, OR = 0.749). This aligns with the reality that university towns and large primary or secondary school campuses are often situated on the periphery or in suburban districts.

(2) Origins reflect "central communities with limited metro access." Residences serving as origins for school trips tend to be closer to the CBD (X13, OR = 0.979) but are more likely to lack nearby metro stations (X9, OR = 0.757). This indicates a spatial pattern in which residents travel from communities near the city center, yet with relatively poor metro accessibility, to suburban campuses with simple road networks and limited transit coverage.

(3) Effect of mixed land use. A marginally significant trend suggests that school trips are more likely to originate in mixed-use residential communities (X7, OR = 1.541). This may reflect the role of better living conditions and improved public service facilities in supporting residents' travel behaviors.

3.3. Multinomial logistic regression model specification

A unified multinomial logistic regression model was constructed to supplement and validate the four independent binary logistic regression models. This approach enables a comparative examination of how built environment variables influence the choice among the four travel purposes.

The dependent variable was "travel purpose," categorized into Commuting (n = 1,550), Shopping (n = 900), Leisure (n = 1,164), and Attending School (n = 467). Given its largest sample size and strongest regularity, Commuting was designated as the reference category. Accordingly, all model results are interpreted as the probability of selecting another travel purpose relative to commuting.

The independent variables comprised those validated in the four binary logistic regression models. Specifically, 14 pre-processed variables were retained, along with the quadratic term variable ($X15 = X14^2$) introduced to capture potential nonlinear effects.

3.3.1 Overall model evaluation

The final multinomial logistic regression model was found to be highly statistically significant (see Table 4). The LRT ($\chi^2(42) = 470.498$, $p < 0.001$) confirmed that residents' choices among different travel purposes can be effectively explained by the independent variables as a whole. The model achieved a Nagelkerke R^2 value of 0.117, indicating that 11.7% of the variance in travel purpose choice is accounted for by the selected variables. Despite its overall statistical significance, the model exhibited limitations in predictive performance. While the predictive accuracy for Commuting reached 68%, the overall accuracy was only 41.68%. Notably, the predictive accuracy for Attending School was close to 0%, suggesting that the built environment variables included in this study lack sufficient explanatory power to effectively distinguish school trips from commuting trips. Nevertheless, the model demonstrates reasonable effectiveness in differentiating other travel purposes.

Table 4. Results of multinomial logistic regression model.

Independent Variable	Shopping VS Commuting			Leisure VS Commuting			Schooling VS Commuting		
	Regression Coefficient	Odds Ratio	P-value	Regression Coefficient	Odds Ratio	P-value	Regression Coefficient	Odds Ratio	P-value
X1 Road network density at origin	—	—	—	-0.014**	0.986	0.02	—	—	—
X2 Road network density at destination	-0.009	0.991	0.136	0.026***	1.026	0	-0.015*	0.985	0.058
X3 POI density at origin	-0.001**	0.999	0.016	—	—	—	—	—	—
X4 POI density at destination	0.006***	1.006	0	—	—	—	0.002***	1.002	0.001
X5 Intersections density at origin	0.001***	1.001	0.004	—	—	—	0.001	1.001	0.154
X6 Intersections density at destination	-0.001**	0.999	0.034	—	—	—	—	—	—
X7 POI mix entropy at origin	—	—	—	0.586**	1.796	0.028	0.583*	1.791	0.097
X8 POI mix entropy at destination	1.283***	3.607	0	—	—	—	—	—	—
X9 Presence/Absence of subway station at origin	—	—	—	—	—	—	-0.278*	0.757	0.086
X10 Presence/Absence of subway station at destination	0.486***	1.626	0	-0.868***	0.42	0	-0.338**	0.713	0.042
X11 Bus stop density at origin	0.044**	1.045	0.021	0.04**	1.041	0.025	—	—	—
X12 Bus stop density at destination	-0.155***	0.857	0	-0.159***	0.853	0	-0.081***	0.922	0.001
X13 Distance from origin to CBD	-0.034***	0.967	0.001	-0.032***	0.969	0.001	-0.037***	0.963	0.002
X14 Distance from destination to CBD	0.143***	1.154	0	0.108***	1.114	0	0.093***	1.098	0
X15 Squared distance to CBD from destination	-0.003***	0.997	0	-0.003***	0.997	0	-0.001**	0.999	0.048
Only variables with P<0.2 are displayed									

Note: ***p < 0.0l, **p < 0.05, *p < 0.1.

3.3.2 Key influencing factor analysis

1. Core factors differentiating "Shopping" from "Commuting":

Compared with commuting, shopping trips are more strongly influenced by the characteristics of the destination environment. The most significant factors include the presence of multi-functional spaces (X8, OR = 3.827) and metro station accessibility at the destination (X10, OR = 1.667). This indicates that, relative to routine commuting, shopping trips are more likely to be directed toward large commercial centers that combine diverse business formats with well-developed public transit services.

2. Core factors differentiating "Leisure" from "Commuting":

Compared with commuting, leisure trips exhibit "anti-commuting" characteristics in terms of destination features. Significant negative associations were observed for the presence of a metro station (X10, OR = 0.422) and destination public transit station density (X12, OR = 0.857), indicating that leisure destinations are often situated away from major public transit hubs. In contrast, multi-functional spaces at the origin (X7, OR = 1.692) exert a significant positive influence, suggesting a spatial pattern in which residents travel from vibrant, well-equipped communities to open spaces with relatively limited transport accessibility.

3. Core factors differentiating "Attending School" from "Commuting":

Compared with commuting, trips for attending school display a distinct spatial pattern. Origins are generally located closer to the CBD (X13, OR = 0.961), while destinations are situated farther from the CBD (X14, OR = 1.062), reflecting the typical reality of "homes in the city, schools in the suburbs." In addition, both commuting and school trips are associated with areas characterized by low public transit station density (X12, OR = 0.921) and limited metro accessibility (X10, OR = 0.720). This underscores the continued importance of conventional bus transit in linking residential areas with suburban educational facilities.

3.4. Comprehensive discussion and conclusion

(1) Heterogeneous influences of the built environment: The effects of built environment variables on travel purposes are not uniform but exhibit distinct "functional profiles." Shopping trips are strongly oriented toward multi-functional commercial hubs located in city sub-centers. Commuting trips display a dual concentration pattern, with flows toward both the central urban area and suburban industrial parks. Leisure trips demonstrate an opposite trend, flowing from vibrant central zones to peripheral open spaces (e.g., parks and green spaces). Trips for attending school reveal a clear spatial separation between central residential areas and suburban educational facilities.

(2) Nonlinear distance effects: The role of distance is not strictly linear. Shopping trips exhibit a significant "inverted U-shaped" relationship with distance to the city center, while commuting trips display a significant "U-shaped" effect. These findings highlight the presence of a polycentric urban spatial structure in Jinan.

(3) Differences in dependence on transit modes: The reliance on public transit varies considerably across travel purposes. Shopping trips are strongly driven by metro accessibility, whereas commuting and leisure trips tend to be negatively associated with metro access. In contrast, conventional bus transit plays an indispensable role, acting like a "capillary system", in supporting school trips, providing important empirical insights for coordinating urban educational resource allocation with the public transit network.

(4) Limited explanatory power for school trips: In the multinomial logistic regression model, school trips could not be effectively distinguished based on built environment variables alone. This suggests that such trips are more strongly shaped by school district boundaries, the spatial distribution of educational

resources, and other unobserved factors not captured in this study.

4. Strategies for optimizing multi-purpose transit trip environment

This section outlines strategies for optimizing the built environment to support multi-purpose transit trips, shopping, commuting, leisure, and attending school, by identifying the key influencing factors associated with each purpose, while considering the distinctive characteristics of Jinan's central urban area.

4.1. Purpose-based transit-oriented development (TOD) model

The demands on the built environment vary substantially across travel purposes, indicating that diverse travel needs cannot be adequately met through traditional "one-size-fits-all" TOD development models. Accordingly, it is recommended that urban planning shift from a strategy of "homogenized coverage" to one of "differentiated supply." For city sub-centers driven by shopping trips, the TOD concept should be strengthened, reflecting the strong preference of shopping trips for multi-functional spaces (X8) and metro accessibility (X10). This entails actively developing multi-functional spaces around metro stations in small-block patterns, enhancing pedestrian environments, and creating vibrant regional commercial cores. For suburban industrial parks driven by commuting trips, given the high reliance on the conventional public transit network (X12) and the observed U-shaped distance effect, it is essential to optimize services such as bus rapid transit and feeder buses connecting residential areas and industrial parks. This approach promotes seamless integration of public transit across different levels, rather than merely replicating city-center TOD models.

4.2. Optimizing urban spatial structure and forming a networked polycentric city pattern

A non-linear relationship observed for commuting and shopping trips provides strong empirical support for the polycentric spatial structure of Jinan. Planning strategies should be aligned with this trend. For city sub-centers identified by the "inverted U-shaped" pattern in shopping trips, policy support should focus on enhancing public services and cultural amenities, as well as creating additional employment opportunities. This approach can transform these areas from purely commercial hubs into multi-functional "micro-cities," thereby shortening trip distances and promoting a better job-housing balance. In the development of residential districts or industrial parks on the urban periphery, public transit connections to existing employment centers, both city centers and sub-centers, should be fully integrated. This ensures efficient access and helps prevent the emergence of a car-dependent "pendulum" commuting system.

4.3. Enhancing connection between "blue-green space" and conventional public transit, and improving urban quality of life

The study identifies a spatial mismatch in leisure trips, characterized by flows from vibrant central zones to open spaces with limited public transit services. This indicates that residents' demand for accessing "blue-green spaces" via public transit is not fully met. It is recommended to establish or optimize direct "leisure routes" or holiday bus services connecting large residential communities and central urban areas to major parks, waterfronts, and scenic areas. These measures would increase service frequency and reduce the need for transfers. Additionally, when constructing or upgrading urban parks, transit station accessibility should be prioritized. Safe and convenient transit parking facilities and pedestrian passageways near park entrances can help bridge the "last mile" gap, improving the overall accessibility of public transit for leisure trips.

4.4. Aligning school districts with public transit networks, ensuring efficiency and equity in trips of attending school

A key finding is the strong reliance on conventional public transit and the relative disconnection from rail networks in trips for attending school, revealing a misalignment between urban educational facilities and transport planning. Public transit accessibility should be a prerequisite consideration in school siting and school district division, requiring close coordination with transport authorities. Given the distinct "pendulum" commuting pattern of school trips, it is recommended that public transit operators introduce new direct "school routes" linking large residential communities with educational zones. Additionally, transit stations near schools should be upgraded with covered walkways and safe crossing facilities to ensure student safety. Implementing these measures can improve the efficiency and convenience of school travel, while also serving as an important strategy to promote educational equity.

5. Conclusion

This study has several limitations. It primarily focused on objective measures of the built environment in Jinan's central urban area, without fully accounting for residents' socio-economic characteristics or perceptual factors. Future research could adopt a multi-source data fusion approach, integrating novel data collection methods such as sensors and GPS traces to capture travelers' subjective perceptions and behaviors. Moreover, the complex mechanisms linking the built environment with transit trips of different purposes could be further elucidated by incorporating a broader set of built environment indicators or more finely categorized travel purposes. Such analyses would help identify precise intervention points for different trip types, providing a robust theoretical and practical foundation for differentiated, targeted public transit service planning and urban space optimization.

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