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Analyses of Multiple Factors Affecting Residents′ Walking to rail Transit Stations in Los Angeles Metropolitan, United States

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Abstract: Taking Los Angeles Metropolitan, United States as the case study, depending on the data from the regional household travel survey conducted during 2011-2013 by the Southern California Association of Governments, the logistic regression models is used to find significant factors that affect residents′ walking to the rail transit stations. Results show that the distance to stations, the continuity of sidewalks, density of street lights, density of street trees, station parking and land use mix are the significant environment factors; meanwhile, the travel destinations, household income, the number of household vehicles and ethnicity are also significantly factors influencing residents′ walking to rail transit stations.

Keywords: walking; rail transit oriented development; metropolitan; multiple factors analysis; logistic regression models; Los Angeles City

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美国洛杉矶大都市影响居民步行到轨道交通站点的多因素分析

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摘要: 以美国加利福尼亚州的洛杉矶市为例,根据 2011—2013 年美国南加州政府联盟提供的居民出行数据,应用逻辑回归模型寻找影响居民步行到快速公交站点的显著因子.结果表明:到达站点的距离和人行道的连续性、路灯密度、行道树密度、站点周边停车和土地混合度是显著影响的居民步行到站点的环境因子;而出行目的地、家庭收入、家庭拥有私家车数量,以及种族等其他因子也显著影响到居民是否步行到站点.

关键词: 步行; 公交导向型发展; 大都市; 多因素分析; 逻辑回归模型; 洛杉矶市

Car dependence can have detrimental effects on the environment and public health, such as increasing green house gas (GHG) emissions, traffic congestion, oil price vulnerability, and physical inactivity[1-2]. Reliant on public transit is one of the success policies toreduce car travel and car dependence[3]. Public transit is generallynot a point-to-point mode of travel, which may incorporate regular physical activities into daily life. A large body of cross-sectional studies found that transit users have higher levels of walking compared to those who do not use transit[4-7]. Numerous studies have found that people are more likely to walk in the neighborhoods with certain environmental characteris-

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tics, especially for transportation purpose[6-9]. Walkable neighborhoods are often characterized by medium-to-high population density, a mix of land uses, high connectivity, and presence of pedestrian infrastructure[10-14].

With more concerns on the transit orient development (TOD), walking to transit also get more attention than before[15-19]. There were very few researches of examining walking to transit, and most of them have involved the similar conceptual models as other travel behavior research[20-23]. To fill in the research gap, this study would introduce groups of predictors, including socioeconomic factors of station areas, built environment factors of station areas and socio-demographic factors of individuals, as well as other factors to predict walking to transit. Meanwhile, not as most previous studies using subjective recall questionnaires, this study employed the travel data that were collected through time diaries, which could avoid recall bias and social-desirability bias[24-25]. The results from this study would provide meaningful suggestions for future TOD practice in metropolitan areas not only limited in the North America, but for worldwide.

1 Research Design

1.1 Study Area

The study area is the city of Los Angeles, which is the most populous city in the state of California and the second largest city in the United States with a population of 3 792 621 from the 2010 census[26]. Based on the number of daily riders, the city's subway system is the ninth busiest in the United States and its light rail system is the country's second busiest[22]. The rail system includes the subway lines (red and purple) and the light rail lines (gold, blue, expo, and green)[22] (Figure 1).

Fig. 1 Metro rail system in Los Angeles City

图 1 洛杉矶市地铁轨道系统

As one of the most economically and ethnically diverse regions in the country, Los Angeles's transit station areas encompass a wide range of demographic, physical, and economic characteristics[16]. The transit network of Los Angeles City extends to various neighborhoods with different household income levels, different rates of car ownership and diverse ethnic populations[16]. Table 1 illustrates the demographic characteristics among regions, cities and transit station areas (half-mile buffers of stations). (Source: *Center for Transit-Oriented Development*, 2011). It indicates that households with lower incomes and lower rates of car ownership tend to live closer to transit stations and take more transit trips or other non-motorized trips than other households.

Tab. 1 Regional, city and station area demographic characteristics of Los Angeles City in 2010

表 1 2010 年洛杉矶市的区域、城市和车站地区的人口特征

Measure	Los Angeles County	City of Los Angeles	Los Angeles station areas
Percentage of trips to work by taking transit, walking, and biking/%	8	14	24
Percentage of households with 0 or 1 car/%	46	57	66
Median household income/dollars	45 280	36 687	29 726
Percentage of renter households/%	46	61	73
Average household size	3.00	2.83	3.02

1.2 Unit of Analysis and Data Source

Most previous researches used 400 meters (0.25 miles) or 800 meters (0.5 miles) as the walking distance to rapid transit stations, which means that the unit of analysis is often centered by the station with 400 meters or 800 meters as the radius[8,21,23,27]. Based on the literature review and the characteristics of data source, this research defines 400 meters (0.25 mile) radius buffer centered by each station as the spatial unit of analysis.

The socioeconomic variables and socio-demographic variables were obtained through regional household travel survey conducted from 2011 to 2013 by the Southern California Association of Governments (SCAG) survey and census data. The other variable was achieved through SCAG survey. The built environment variables were all objective ones and measured using geography information system (GIS), which were gotten through multiple data sources, including Los Angeles County GIS portal, Los Angeles County sheriff, City of Los Angeles Department of Transportation (LADOT), and U.S. Geological Survey (USGS). The network analyst tool would be employed to measure the connectivity of streets; the proximity tool (buffer) and extract tool (clip) extract the attributes in 400 meter/quarter mile buffers; and the summarize function in the attribute table get the results we need.

1.3 Research Method

There are four groups of predictors in the analysis, including built environment attributes (both continuous and categorical variables), individuals' socio-demographic attributes (both continuous and categorical variables), socioeconomic attributes of station areas (continuous variables) and other variable (travel destination) (categorical variable). Here, one group of predictors was added in the new model in a stepwise approach and finally four logistic regression models were produced. The models (1), (2), (3) and (4) would be stated as follow.

$$N = \beta_0 + \beta_1 A + \mu, \tag{1}$$

$$N = \beta_0 + \beta_1 A + \beta_2 C, \tag{2}$$

$$N = \beta_0 + \beta_1 A + \beta_2 C + \beta_3 S + \mu, \tag{3}$$

$$N = \beta_0 + \beta_1 A + \beta_2 C + \beta_3 S + \beta_4 B + \mu. \tag{4}$$

In here, N mean walking to transit, A means other variable (travel destination), B means built environment variables, C means socioeconomic variables of units of spatial analysis, S means socio-demographic variables of individuals, μ=regression error term.

The first model only has other variable, the second model has both other variable and socioeconomic attributes of station areas, the third one has three groups of predictors while adding the socio-demographic factors of individuals in, and the final model adds the group of built environment predictors. In the final model, walking to transit is regressed on four groups of independent variables.

2 Data Analysis and Results

2.1 Descriptive Analysis

Total number of 745 individuals' records in the Southern California Association of Governments (SCAG) household travel survey are completed and valid for this research and total 55 transit stations are involved for the records above. Descriptive analysis is performed for the spatial unit of analysis (400 meters distance from the rail stations). Mean and standard deviation (SD) are calculated for the 20 independent variables and they are displayed in Table 2. In table 2, "(c)" means categorical variables, N=745 is total number of individuals, N=55 is transit stations involved.

2.2 Results

To determine the significant factors that impact the walking behavior to transit stations, four binary logistic regression models were employed to do the analysis (see table 3). In table 3, "(c)"

Tab. 2 Descriptive statistics of independent variables

表2 自变量的描述性统计表

Independent variables	N	Description or coding	Mean	Std. deviation
Travel destination (c)	745	1=utilitarian, 0=recreational	0.80	0.398
Age	745	Years of age	38.82	14.637
Gender	745	1=male, 0=female	0.37	0.484
Household income (2010) (c)	745	Less than \$10 000, \$10 000 to 49 999, \$50 000 to \$74 999, \$75 000 or more	2.11	0.876
Household vehicle number	745	number of household vehicles	0.85	0.833
Employment status (c)	745	1=employed, 0=unemployed	0.44	0.240
Ethnicity (c)	745	1=non-hispanic white, 0=others	0.18	0.385
Education (c)	745	11th grade or less, High school graduate, 2 years of college/associates degree, 4 years of college/bachelor′s degree, Post-graduate	2.56	1.268
Black percentage	55	Number of black/total population of each unit/%	16.45	17.648
Hispanic percentage	55	Number of hispanic/total population of each unit/%	35.51	20.558
Median household income	55	Income in dollars	38 489.53	16 468.576
Distance (100 feet)	745	Distance from home to transit stations	15.64	6.832
Sidewalk completeness	55	Total miles of sidewalks/(total length of streets×2)/%	44.29	17.590
Street lights density (number/mile)	55	Total number of street lights /(total length of streets×2)	39.62	16.073
Trees coverage density (number/mile)	55	Total number of trees /(total length of streets×2)	44.29	17.596
Transit station parking (c)	55	1-avaliable, 0-not available	0.53	0.499
Street density (100 feet/acre)	55	Total feet of streets/total acres of area	24.69	6.320
Intersection density	55	Number of street intersections (≥3-way)/total acres of area	0.16	0.085
Land use mix	55	Land use mix $=-[(\sum_i^n(p_i)\ln(p_i))/\ln(n)]$, p - proportion of sq. ft of landuse i, n - No. of land uses	0.61	0.183
Residential density	55	Total residential population/total acres of area	7.64	1.708

means categorical variables, OR representing odd ratio, Coeff. representing coefficient. The first model only has travel destination as the predictor, which is significant to predict the walking behavior to stations. Traveling to utilitarian destinations decreased the likelihood of walking to stations by 0.260 times compared with traveling to recreational destinations. Traveling destination maintained statistical significance in all of the four models.

The socioeconomic variables of station areas include black percentage, Hispanic percentage and median household income. While adding the socioeconomic variables of station areas in the second model, none of them were significant. The median household income variable turned into significance in model 3 and one level increased in the median household income would increase the likelihood of walking to stations by 1.313 times. It became more significant in the final model, with a one level increasing the median household income increasing the likelihood of walking to stations by 1.636 times. However, the percentage of black and percentage of Hispanic was not significant in the following models.

Tab. 3　Results of four logistic regression models predicting walking to transit stations

表 3　4 个逻辑回归模型预测步行到站点的结果

Independent variables	Model 1			Model 2			Model 3			Model 4		
	P	Coeff.	OR	P	Coeff.	OR	P	Coeff.	OR	P	Coeff.	OR
Other variable												
Travel destination (c)	0	−1.349	0.260***	0	−1.384	0.250***	0	−1.556	0.221***	0	−1.469	0.230***
Socioeconomic variables of station areas												
Black percentage	—	—	—	0.135	0.009	1.009	0.061	0.011	1.011	0.064	0.020	1.021
Hispanic percentage	—	—	—	0.073	0.011	1.011	0.136	0.007	1.007	0.162	0.008	1.008
Median household income	—	—	—	0.195	0.141	1.152	0.022	0.272	1.313*	0.004	0.492	1.636**
Socio-demographic variables of individuals												
Number of household vehicle	—	—	—	—	—	—	0.001	−0.342	0.714***	0.026	−0.264	0.768*
Household income(c)	—	—	—	—	—	—	0	−0.369	0.692***	0	−0.488	0.614***
Age	—	—	—	—	—	—	0.053	−0.022	0.992	0.052	−0.029	0.989
Gender(c)	—	—	—	—	—	—	0.690	−0.072	0.930	0.051	−0.254	0.776
Employment(c)	—	—	—	—	—	—	0.508	−0.116	0.890	0.621	0.137	1.099
Ethnicity(c)	—	—	—	—	—	—	0.001	−1.026	0.359***	0	−0.864	0.421***
Education(c)	—	—	—	—	—	—	0.053	0.135	1.145	0.081	0.132	1.414
Built environment and safety variables												
Distance	—	—	—	—	—	—	—	—	—	0	−0.081	0.922***
Sidewalk completeness	—	—	—	—	—	—	—	—	—	0.004	0.020	1.020**
Street lights density	—	—	—	—	—	—	—	—	—	0.022	0.027	1.028*
Trees coverage density	—	—	—	—	—	—	—	—	—	0.042	0.007	1.007*
Transit station parking(c)	—	—	—	—	—	—	—	—	—	0.015	−0.531	0.588*
Street density	—	—	—	—	—	—	—	—	—	0.180	0.002	1.002
Intersection density	—	—	—	—	—	—	—	—	—	0.224	0.175	1.186
Land use mix	—	—	—	—	—	—	—	—	—	0.028	0.135	1.145*
Residential density	—	—	—	—	—	—	—	—	—	0.429	0.007	1.007
Constant	0	2.327	10.242	0.001	1.447	4.252	0.001	0.867	2.472	0.845	0.261	1.299
Number of observations	—	745	—	—	745	—	—	745	—	—	745	—
Model fit												
−2 log likelyhood		942.614			916.402			859.704			751.809	
Nagelkerke R^2		0.081			0.125			0.216			0.370	

*: $P<0.05$; **: $P<0.01$; ***: $P<0.001$.

In model 3, vehicle number of household, household income, and ethnicity are the significant indicators to impact walking behavior to stations. Here the ethnicity was a dummy variable (white=1).

While one vehicle increased in the household, the likelihood of the individual walking to stations decreased by 0.714 times. The availability of cars in household had been tested as an important variable for encouraging driving and decreasing walking in early studies.

There are total six significant built environment factors to predict walking to stations. The distance and percentage of sidewalk completeness were the two most significant ones. The distance is the spatial distance from the departure origin to the station destination and the unit in this analysis is 100 feet. With one hundred feet increasing distance, it decreased the likelihood of walking to stations by 0.922 times. While one percentage increased in the sidewalk completeness, the likelihood of walking to stations increased by 1.020 times. Consistent with previous findings, the availability of sidewalks to stations decided the possibility of walking to stations.

The street lights density, trees coverage density, transit station parking and land use mix were other four built environment factors that impact the walking to stations significantly. Street lights are essential street facilities for the safety of walkers at night and trees shade is essential for walking in summer. While adding one street light per mile, the likelihood of walking to stations could increase by 1.028 times. While adding one street tree per mile, the likelihood of walking to stations could increase by 1.007 times. Land use mix was reported as a critical indicator in a great number of previous studies for encouraging walking, the same findings in this study. Every 0.1 increase in the land use mix index (0-1), it increased the likelihood of walking to stations by 1.145 times. Transit station parking was indicated as a significant negative indicator in early researches and it is also a negative significant factor in this analysis. The stations with parking would decrease the likelihood of walking to stations by 0.588 times compared with the stations without parking.

Generally, under model summary, −2 log likelihood statistic measures how poorly the model predicts the decisions, the smaller the value the better the model. In model 1, −2 log likelihood statistics is 942.61, and it decreased in model 2 (916.402) after adding socioeconomic factors of station areas. It continually decreased in model 3 (859.704) while adding socio-demographic variables of individuals. When added the built environment attributes in model 4, the −2 Log Likelihood decreased to 751.809. It is obvious that the models are continually improving the predictive power for the dependent variable.

The maximum value of Nagelkerke R-square is equal to 1.0. Overall, high values are better than low values, higher values suggesting that the model fits increasingly well. In model 1, Nagelkerke R-square is 0.081, which means that 8.1% of the variation in dependent variable (walking to stations) could be explained by travel destination. In model 2, Nagelkerke R-square is increasing to 0.125, which means that after adding in socioeconomic predictors of station areas, the variations of dependent variable (walking to stations) could be explained 12.5% by the model 2 and increased 4.4% compared with model 1. The Nagelkerke R-square in model 3 is 0.216, which explained 21.6% of the variations of dependent variable (walking to stations) after adding socio-demographic factors of individuals and increased 9.1% compared with model 2. In the final model (model 4), Nagelkerke R-square is 0.370. The final model incorporated built environment predictors in and explained 37% variation of the dependent variable, which increased 15.4% compared with model 3.

3 Discussions and Conclusions

3.1 Limitations of This Study

The survey population for the present survey was households with telephones in the Southern California Association of Governments (SCAG) region; however, Census 2010 data indicates that 1.6% of occupied housing units in the SCAG region are without telephones. This survey has conducted through phone, thus some potential respondents were ignored. Meanwhile, the overall response rate was low, only 25 percent, which is primarily due to the complex of interview processes. An important determinant of data quality is the accuracy of the reported trips. To enhance reporting accuracy, this survey relied on diary instruments in which respondents are asked to record each trip for a specific time period (e. g., 24-hours, 48-hours), however, the accuracy of the records are case by case. The Nagelkerke R-square of final model is 0.37, which means that the model can explain 37% variation of the dependent variable. The value is not so high due to other reasons, such as self-selection of residents, which do not matter if they have walkable environment but their preferences.

3.2 Conclusion

The findings of this study indicate that the built environment of station areas has significantly impact on residents' walking to transit. Improving the pedestrian environment of station areas could increase the likelihood of walking to transit, such as increasing sidewalk completeness to make walking possible, adding more street lights for walking safely at night, adding more street trees for walking comfortably in summer, increasing mixed land use for convenient shopping and decreasing parking lots around stations to avoid driving. These findings would be the potential suggestions for policy makers to enhance transit oriented development in future. This research highlights not only built environment indicators, but emphasizes that some variables of socioeconomic characteristics of station areas and socio-demographic variables of individuals also influence walking to transit. It is interesting to find that the households with higher income would have less opportunity walking to stations due to owning the cars, however, the station areas with higher average household income would have more walkable environment. Although the households with high income intend to live in a livable neighborhood, most of them still prefer to using a car instead of walking. Thus, self-selection is very important for individuals if they can afford cars, and the walkable environment is not sufficient for them to choose walking to transit. There need more policies to encourage walking plus taking transit, such as economic incentives.

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