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Original Research

Correlation between Road Network Accessibility and Urban Land Use: A Case Study of Fuzhou City

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Abstract

The correlation between road network accessibility and land use is mainly considered a spatial-topological relationship, thus making it difficult to reveal accurately. In consideration of the road speed limit and network structure, this paper constructed a road network accessibility model based on weighted spatial syntax. A correlation analysis between road network accessibility and land use was then conducted and compared with those based on relative asymmetry (RA) and normalized angular choice (NACH) by regarding the central district of Fuzhou City as an example. Results showed that the roads with good accessibility by RA and NACH were presented as 'grid' roads. The result of road network accessibility by weighted RA and NACH could better reflect the actual effect of road network accessibility than RA and NACH. Furthermore, the road network accessibility by weighted RA and NACH could improve the correlation analysis between road network accessibility and urban land use, especially in NACH. Results could provide a scientific reference for the urban planning and development.

Keywords: geographic information system, normalized angular choice, relative asymmetry, spatial syntax

Introduction

Urban road traffic and land use have a close interaction relation [1-2]. Traffic accessibility plays a key role in the space layout of urban economic and cultural activities [3]. Urban traffic is mainly reflected by the urban road network. Therefore, the study on the relationship between road network accessibility and urban land use change has an important practical significance for urban land use planning.

In view of this problem, several scholars conducted relevant research, which mainly focused on the relationship between traffic accessibility and the spatial layout of urban land use [2-4], the relationship between transportation systems and land use [5-8], the interaction between accessibility and land use [9-14], the impact of traffic roads on regional land use change [15-18] and urban layouts with population, road network or land use

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[19-20]. For example, Shang et al. [2] regarded Huaian City of Jiangsu Province as an example and analysed the characteristics and evolution of urban functional land by using an accessibility analysis technology based on ArcGIS9.3 software. Huang and Hsieh [6] analyzed the relationship between mixed land use and transportation system in Tainan, Taiwan by using the spatial accessibility of road network. In view of the interactive relationship between traffic accessibility and land use, Stanilov [9] analysed the relationship between land use and accessibility according to land use cover changes over 30 years in the suburban areas of Greater Seattle. Tang et al. [11] built an evaluation index system of land use and urban traffic coordination through the relationship between urban traffic and land use and studied the coordination relationship of an urban land transportation-integrated system. From the impact of traffic roads on land use change, Hu et al. [15] indicated that road traffic can affect land use change in surrounding areas by altering traffic accessibility and its degree of impact on road grade, road distance and original land use types. Lyu et al. [19] introduced an urban simulation system to produce urban layouts with land use, road network and population. Zhou et al. [20] quantified the statistical relationship between urban morphology and urban accessibility, and found that increasing the combination of land use could improve urban accessibility.

In summary, the existing calculation methods for road network accessibility are widely used traditionally, and few of them are suitable for fine spatial-scale accessibility research. The space syntax is suitable for the calculation of road network accessibility in fine spatial scales and has been applied to the calculation of the accessibility of subway lines, urban blocks or parks and buildings at the urban scale [21-27]. Nevertheless, the accessibility research based on spatial syntax has mainly considered spatial topological relations, whilst few have considered such factors as actual road speed restriction and network structure grade which could reflect the accessibility differences amongst different road networks precisely. Therefore, accessibility research based on improved spatial syntax should be conducted. In consideration of the road speed limit and network structure, this paper constructed a road network accessibility model based on weighted spatial syntax. The correlation between road network accessibility and land use was studied on the basis of the road network data of the central district of Fuzhou City in 2012. The results were compared with those based on the spatial syntax of relative asymmetry (RA) and normalised angular choice (NACH).

The objectives of this research were (i) to establish a road network accessibility model based on weighted spatial syntax, (ii) to analyze the correlation between road network accessibility and land use and (iii) to compare the correlation between road network accessibility and land use by weighted RA, weighted NACH and RA and NACH.

Materials and Methods

Data Collection and Processing

Data were collected from Google Map, traffic atlas and administrative map of Fuzhou City in 2012. From these data, the vectorgraph of a village administrative map in the central district of Fuzhou City, the land use classification in 2012 and the road network data in 2012 were obtained via projection transformation, editing, splicing and topology checking in ArcGIS 10.2 software. The types of land use were divided into 27 in accordance with the overall land use planning of Fuzhou City (2006-2020) (Fig. 1a). The data of road speed limit were acquired from the laws and regulations of road traffic safety, the regulation on compulsory traffic accident liability insurance for motor vehicles and an actual investigation (Fig. 1b). Pearson correlation coefficient was used to analyse the correlation between road network accessibility and land use by SPSS 20.0 software.

The network centrality characteristic index including degree centrality, close centrality, and intermediate centrality. The network centrality characteristic index could be calculated as follow [26-29]:

(1) Degree centrality [26-29]:

$$L_i^d = \sum_{j=1}^{k} D_{ij} \tag{1}$$

where L^d_i is degree centrality; D_{ij} is value of 1 or 0, when $D_{ij} = 1$, the road chain *i* intersected the road chain *j*; when $D_{ij} = 0$, the road chain *i* not intersected the road chain *j*; *k* is the number of road chain.The larger the value of D_{ij}, the stronger the connectivity of the road chain, and the greater of the whole road network.

(2) Closeness centrality [26-29]:

$$L_i^c = 1 \Big/ \sum_{i \neq j, j=1}^{k} C_{ij} \tag{2}$$

where L^c_i is closeness centrality; C_{ij} is number of road chains passed from road chain *i* to road chain *j*; The larger the value of L^c_i, the stronger the connectivity of the road chain, and the greater of the whole road network.

(3) Betweenness centrality [26-29]:

$$L_i^b = \sum_{j \neq a \neq i}^{k} K_{ja}(i) \Big/ K_{ja} \tag{3}$$

where L^b_i is betweenness centrality; K_{ja} is number of the shortest path between node *j* and *a*; $K_{ja}(i)$ is number of the shortest path passing through node *i*; The larger the value of L^b_i, the stronger its influence and control and the greater of the road.

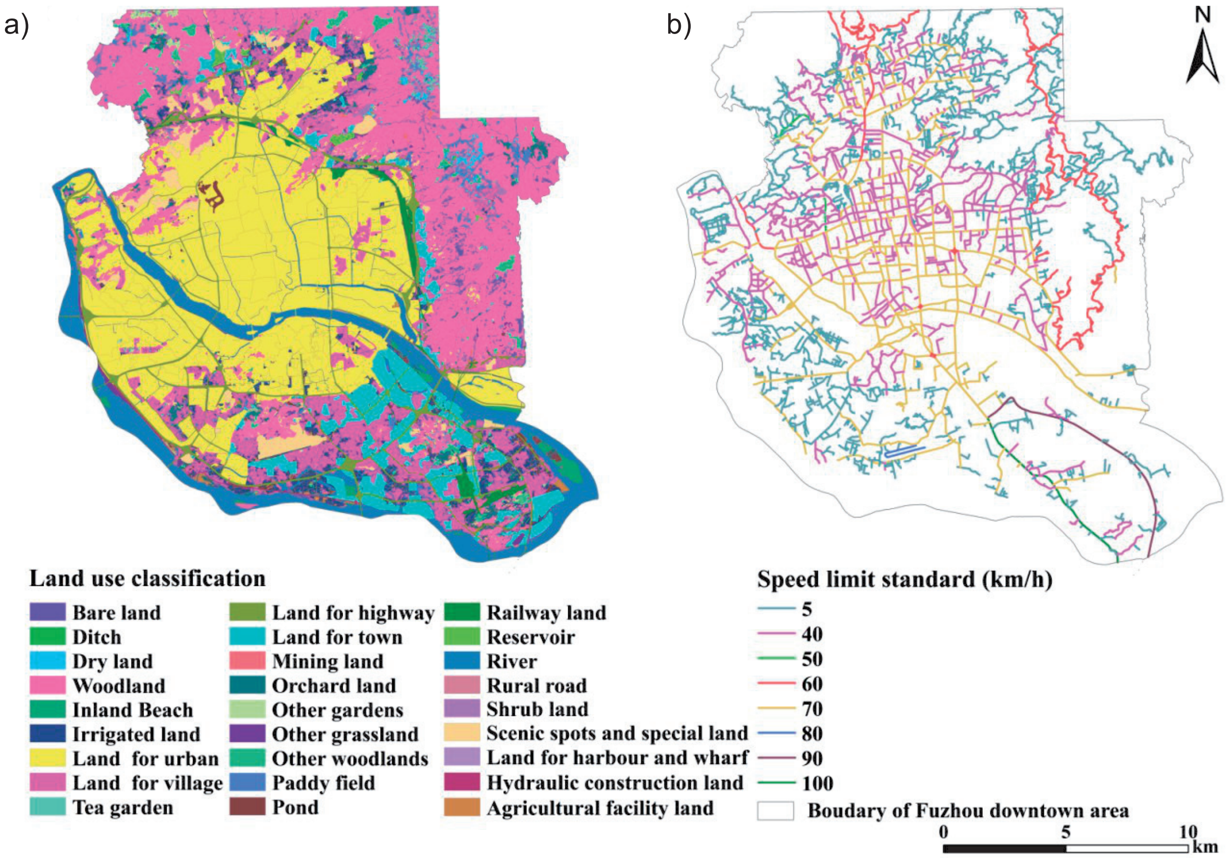

Fig. 1. Land use distribution map and speed distribution map.

Road Chain Length

Drivers often prefer to drive on long straight roads with minimal steering on the basis of vehicle historical trajectories. Therefore, the index of road chain length was also introduced into the structural grade analysis of road network. The road chain length can be calculated as follows [26, 30]:

$$R_a^E = SL(f_{note}, e_{note}) \tag{4}$$

where R_a^E is road chain length; f_{note} is the starting point of road chain a; e_{note} is the end point of road chain a.

Calculation of the Structural Grade of Road Network

On the basis of the results of the central characteristic index and the length index of the road chain, the criterion importance through the intercriterion correlation method was used to integrate the abovementioned indexes. The structural grade of road network can be calculated as follows [26, 30]:

$$L = \sum_{a=1}^{e} (\xi_a \times H_a) \tag{5}$$

where L_i is result of structural grade of road network; H_a (a = 1,2,3,4) is normalization of degree centrality, close centrality, intermediate centrality and road chain length respectively; e is number of index; ξ_a is weight of index; ξ_a could be calculated by Criteria Importance Though Intercrieria Correlation method as follow [30]:

$$\xi_a = F_m \Big/ \sum_{i=1}^{t} F_m \tag{6}$$

$$F_m = \sigma_m \sum_{j=1}^{e} (1 - R_{mj}) \tag{7}$$

where σ_m is standard deviation of evaluation index of m; ξ_a is weight of index; R_{mj} is the correlation coefficient between index m and j.

Road Network Accessibility Model Based on Weighted Spatial Syntax

The three indexes of spatial syntax, namely, RA and NACH, structural grade of road network and restricted speed of road network, were combined. This paper constructed a road network accessibility model based on weighted spatial syntax. The model can be calculated as follows [22, 30-32]:

$$W_i = \sum_{i=1}^{3} (A_i \times \lambda_i) \tag{8}$$

$$RA = \frac{2(\overline{D} - 1)}{n - 2} \tag{9}$$

$$\overline{D} = \frac{\sum_{d=1}^{m} (f_d \times d)}{n - 1} \tag{10}$$

$$NACH = \frac{\log\left(\sum_{i=1}^{g}\sum_{j=1}^{g} \phi(i,v,j) \Big/ (g-1)(g-2)+1\right)}{\log\left(\sum_{i=1}^{g} d(v,i) + 3\right)} \quad i \neq v \neq j \tag{11}$$

where W_i is the result of road network accessibility; *RA* is result of relative asymmetry; A_i (i = 1, 2, 3) is spatial syntax (Relative asymmetry and Normalized angular choice), road network structured level and limited speed of road respectively; λ_i is weight of spatial syntax, road network structured level and limited speed of road; n is the number of axes in road network; $\bar{D}$ is average depth; d is the minimum number of connections from one axis to any other axis in road network; f_d is number of connecting axes; *NACH* is the result of normalized angular choice; g is the total number of street segment; $d(v,i)$ is minimum corner distance from street segment v to street segment i; $\Phi(i,v,j)$ is minimum angle distance for street section i approaching v to j. In this paper, the expert scoring method is used to determine the weight of spatial syntax, road network structured grade and limited speed of road. The values are 0.571, 0.323 and 0.106, respectively.

Results and Discussion

Results of Road Network Accessibility Based on Spatial and Weighted Spatial Syntax

In accordance with the road network data, the results of road network accessibility in the central district of Fuzhou City in 2012 were calculated using Formulas (1)-(11). The results were divided into five grades, namely, very poor, poor, moderate, good and very good accessibility, by using the Jenks natural breaks method. The results are depicted in Fig. 2.

The result of road network accessibility by RA showed that the road network extended from the middle to the outside, indicating limited space convenience (Fig. 2a). RA was the reciprocal of spatial integration, namely, the meaning expressed was contrary to the actual degree of spatial convenience. We could determine from Fig. 2a) that the closer to the middle of the road network was, the better the degree of spatial convenience would be. The results of road network accessibility by weighted RA showed that the roads with good spatial convenience were 'claw' around the 'grid' in the middle of the central district of Fuzhou City, and the roads with poor spatial convenience were mainly distributed in the north, south and southwest of the central district (Fig. 2b). The result of road network accessibility by weighted RA was consistent with the actual situation, which showed that the weighted RA stretched the result of road network accessibility by RA to a practical significance.

From the perspective of NACH (Fig. 2c), the road of good NACH was presented in the form of centre circle and network scattering outwards and distributed in the central and middle northern regions of the central district of Fuzhou City. The road of poor NACH was distributed in the south and southwest of the central district. The road of good NACH by weighted NACH was extended outwards in a 'claw' shape around a 'small grid' in the middle of the central district (Fig. 2d). Compared with the result of NACH, the road of good NACH by weighted NACH were more concentrated in the central region, and the NACH in the north was relatively poor. The number and grade of rural roads in the northern part of the study area were less and lower than those in the central area. Therefore, the NACH of road was low. On the contrary, the weighted NACH of road was good. The road with NACH was poor in the northern region of the central district of Fuzhou City rather than good in the result of NACH from a global perspective. The road coherence of weighted NACH was stronger than that of NACH due to the calculation of NACH based on interrupting axes, leading to unnatural 'breaking' of roads. In view of statistical results (Table 1), the road network accessibility by weighted RA and weighted NACH had improved the accessibility relative to the road network accessibility by RA and NACH.

Generally, the roads with good accessibility by weighted RA and weighted NACH were presented as 'grid' roads, such as main streets and roads, because the main streets and roads had large width and high speed restrictions. The result of road network accessibility by weighted RA and NACH was more realistic than that of road network accessibility by RA and NACH and could better reflect the actual effect of road network accessibility.

Many scholars directly adopted spatial syntactic indicators when studying road network accessibility [12, 31, 33]. However, traditional spatial syntactic indicators are mainly considered from the perspective of road spatial topology, without considering any practical significance, such as road network structure level, driver preference for road characteristics and road chain characteristics. Considering road network structure level and road chain characteristics, this paper established a road network accessibility model based on weighted spatial syntax. The result showed that the roads with good accessibility by weighted RA and weighted NACH were presented as 'grid' roads.

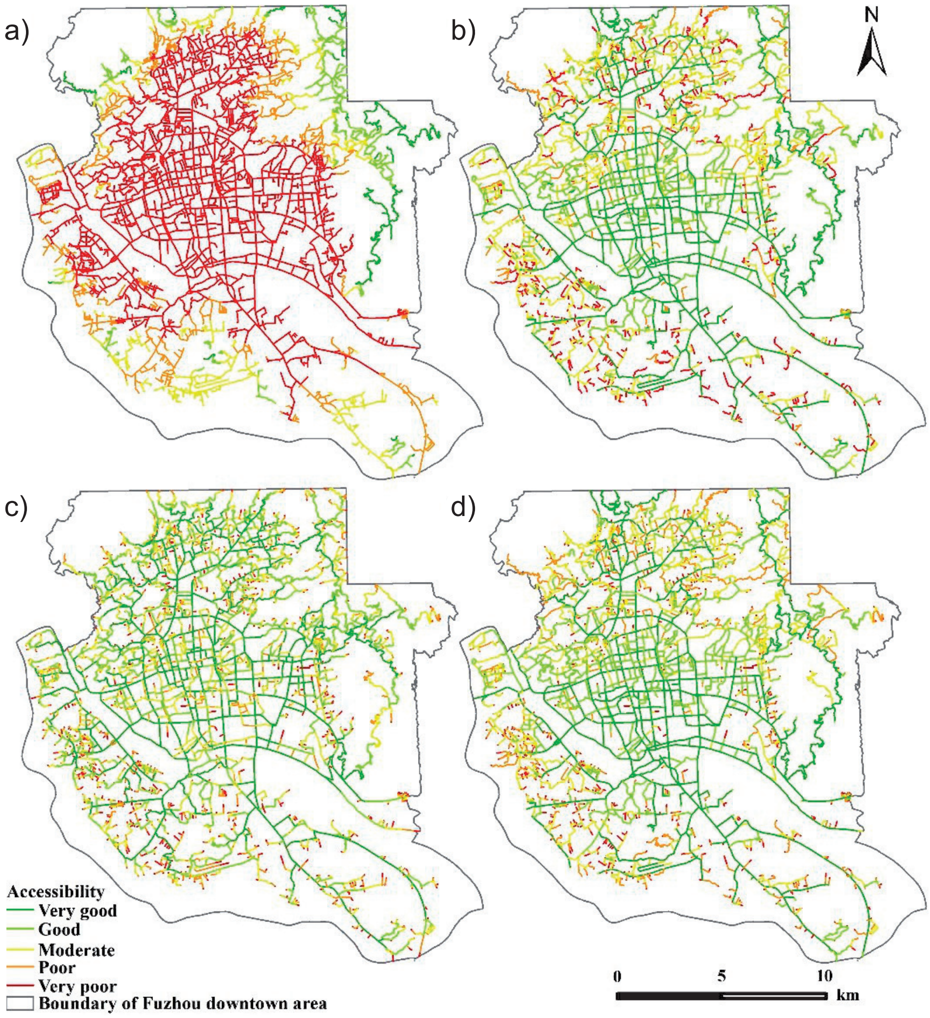

Fig. 2. Results of road network accessibility in central district of Fuzhou city in 2012.

The road networks in China's cities often present ring-shaped radiation, whereas most of foreign road networks often show grid-shaped one. In view of urban planning, the government advocated that the core area of urban economy and finance be concentrated in the city center and gradually developed outwards in the process, resulting in a highly concentrated urban power and a ring radiation pattern. However, the result showed that the accessibility of a circular radial road network was not as good as that of a grid road network in view

Table 1. The statistical results road network accessibility by RA and NACH and weighted RA and weighted NACH.

Accessibility		RA	Weighted RA	NACH	Weighted NACH
Very good	Length (m)	59877.48	498501.23	416992.41	478844.12
	Proportion (%)	4.59%	38.23%	31.98%	36.73%
Good	Length (m)	84897.12	234137.90	369645.57	290314.22
	Proportion (%)	6.51%	17.96%	28.35%	22.27%
Moderate	Length (m)	193940.92	325380.14	294001.42	302327.62
	Proportion (%)	14.88%	24.96%	22.55%	23.19%
Poor	Length (m)	224642.08	97942.98	157957.07	179085.48
	Proportion (%)	17.23%	7.51%	12.16%	13.73%
Very poor	Length (m)	740423.83	147819.18	65184.96	53209.99
	Proportion (%)	56.79%	11.34%	5%	4.08%

Table 2. The correlation analysis result between road network accessibility and urban land use in central district of Fuzhou city in 2012.

Name of land type	Code of land type	RA		NACH	
		Spatial syntax	Weighted spatial syntax	Spatial syntax	Weighted spatial syntax
Mining land	204	0.555**	0.551**	0.126*	0.540**
Tea garden	022	0.197**	0.176**	-0.001	0.179**
Land for urban	201	0.657**	0.742**	0.101	0.739**
Land for village	203	0.367**	0.401**	0.046	0.411**
Scenic spots and special land	205	0.459**	0.531**	0.003	0.545**
Land for harbour and wharf	106	0.570**	0.571**	0.119	0.553**
Land for highway	102	0.676**	0.725**	0.094	0.726**
Ditch	117	0.294**	0.329**	0.006	0.335**
Shrub land	032	0.519**	0.460**	0.023	0.471**
Orchard land	021	0.409**	0.391**	0.062	0.403**
Dry land	013	0.523**	0.479**	0.003	0.488**
River	111	0.299**	0.316**	0.044	0.323**
Land for town	202	0.454**	0. 484**	0.070	0.486**
Pond	114	0.282**	0. 323**	0.026	0.337**
Bare land	127	0.849**	0.841**	0.168**	0.823**
Inland Beach	116	0.219**	0.231**	0.051	0.239*
Rural road	104	0.815**	0.827**	0.085	0.831**
Other grassland	043	0.433**	0.459**	0.043	0.467**
Other woodlands	033	0.328**	0.304**	0.076	0.322**
Other gardens	023	0.115	0.113	0.027	0.112
Agricultural facility land	122	0.529**	0.555**	0.054	0.558**
Hydraulic construction land	118	0.235**	0.251**	-0.012	0.259**
Irrigated land	012	0.290**	0.307**	0.016	0.320**
Reservoir	113	0.111	0.101	-0.002	0.111
Paddy field	011	0.547**	0.465**	0.040	0.468**
Railway land	101	0.562**	0.585**	0.125*	0.578**
Woodland	031	0.950**	0.921**	0.142*	0.914**

**. Significant correlation at 0.01 level (bilateral),*. Significant correlation at 0.05 level (bilateral).

of road network accessibility. The result also showed that the road network accessibility by weighted RA and NACH could better reflect the actual effect of road network accessibility than that by RA and NACH.

Correlation Analysis Result between Road Network Accessibility and Urban Land Use in The Central District of Fuzhou City

The correlation between road network accessibility and urban land use was analyzed and compared on the basis of the results of road network accessibility by spatial and weighted spatial syntax in the central district of Fuzhou City in 2012. The results are presented in Table 2.

In view of RA and weighted RA, the results showed that the road network accessibility in the central district was strongly correlated with most types of urban land use, including mining land, tea garden, land for urban, land for highway, bare land, agricultural facility land, woodland, scenic spots and special land, land for village and rural road ($P<0.01$). Amongst them, bare land, rural road and woodland had a strong correlation with road network accessibility in the central district, and the correlation coefficients were over 0.8. They were followed by the land for urban and land for highway, in which the correlation coefficient was over 0.6. Only the other gardens and reservoirs had no correlation with road network accessibility. Compared with the correlation result by RA, that by weighted RA had a small increase in the correlation between road network accessibility and urban land use in general.

From the perspective of NACH and weight NACH, the results showed that the road network accessibility by NACH in the central district had no correlation with most types of urban land use. Only the mining land, bare land, railway land and woodland had a weak correlation with road network accessibility. By contrast, the road network accessibility by weighted NACH in the central district was strongly correlated with most types of urban land use, such as mining land, land for urban, land for highway, bare land, agricultural facility land, woodland, land for village and rural road ($P<0.01$). In particular, bare land, rural road and woodland had a strong correlation with road network accessibility, and the correlation coefficients were over 0.8. They were followed by land for urban and land for highway, in which the correlation coefficient was over 0.7. Only the other gardens and reservoirs had no correlation with road network accessibility. Compared with the correlation result by NACH, that by weighted NACH had significantly improved in the correlation between road network accessibility and urban land use.

In summary, the road network accessibility by weighted spatial syntax could improve the correlation analysis between road network accessibility and urban land use, especially in NACH. Compared with the correlation result by the spatial syntax, the correlation result by the weighted spatial syntax could improve in the correlation between road network accessibility and urban land use in this paper. The result showed that the road network accessibility by the weighted spatial syntax could reveal the correlation more accurately than the road network accessibility by the spatial syntax did.

Conclusions

This paper established a road network accessibility model based on weighted spatial syntax combined with road speed limit and network structure level. On this basis, the correlation analysis between road network accessibility and land use was conducted and compared with those based on RA and NACH, with the central district of Fuzhou City as an example. The results showed that the roads with good accessibility by RA and NACH were presented as 'grid' roads. The result of road network accessibility by weighted RA and NACH could better reflect the actual effect of road network accessibility than that by RA and NACH.

In view of RA and weighted RA, the road network accessibility was strongly correlated with most types of urban land use. From NACH and weighted NACH, the road network accessibility by NACH had a weak correlation with mining land, bare land, railway land and woodland. By contrast, the road network accessibility by weighted NACH was strongly correlated with most types of urban land use. The result also showed that the road network accessibility by the weighted spatial syntax could improve the correlation analysis between road network accessibility and urban land use, especially in NACH. Combined with Fig. 1, it can be found that the road speed limit and network structure has a significant effect on road accessibility. Therefore, the road surrounding land types must be taken into consideration to design road grades and speed limit standards when constructing or improving roads. In addition, the roads in the corresponding area can be classified in a refined manner during land use planning. In short, land use planning and road design processes complement each other in order to achieve the goal of sustainable development. The results could provide a planning reference for the urban planning and development.

However, the expert evaluation method was used to determine the weights of three factors in the road network accessibility model, which inevitably had some subjectivity and needed further improvement in the future study. In addition, this paper only considered RA and NACH. Other indexes, such as integration, selectivity and control, needed to be studied further.

Acknowledgments

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Conflict of Interest

The authors declare no conflict of interest.

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