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Study on the relationship between traffic dominance and land use efficiency in Shanghai

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ABSTRACT

Transportation infrastructure promotes the interconnection of production factors between regions and enhances the efficiency of land use, while land use patterns also have an impact on transportation development patterns and mixes. Although the development of different regions within megacities tends to be integrated, different transportation mixes and land inputs still bring differentiated dynamics to the development of the blocks. In order to explore the relationship between regional traffic conditions and land use efficiency, this paper investigates the traffic development conditions and land use efficiency of each district in Shanghai by using the traffic dominance degree model and the three-stage Super-SBM model, and explores the relevant role relationship between them by using the coupled coordination degree model. The results show that: (1) the central city has the highest traffic dominance, and the suburban areas, especially the distant suburban areas, have low traffic dominance; (2) the land use efficiency of the eastern area of Shanghai is significantly higher than that of the western area, and the land use efficiency of the southern area is higher than that of the northern area; (3) in terms of coupling coordination, the traffic development and land use efficiency of most districts are coordinated, but the degree of coordination varies greatly, with Huangpu District, Yangpu District, Pudong New Area, and Hongqiao District. Yangpu District, Pudong New Area and Hongkou District are at a high level of coordinated development, Chongming District and Changning District are at an uncoordinated development, and the rest of the districts are at a medium level of coordinated development.

Keywords: Traffic dominance, land use efficiency (LUE), three-stage Super-SBM model, output orientation

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1. Introduction

Transportation infrastructure plays an important role in molding the configuration of the spatial socio-economic structure and influences the accessibility of this region. In recent years, with the development of China's urbanization and regional integration process, transportation has become an important driving force for economic development. Scholars have been evaluating the merits of traffic for a long time. The early indicator for evaluating the merits of traffic was accessibility, and Hansen first proposed the concept of accessibility in 1959, aiming to study the magnitude of the opportunities for interaction between nodes in a traffic network [1]. On this basis, Jin Fengjun proposed the concept of transportation superiority degree, studied the pros and cons of transportation through the three dimensions of quality, quantity and advantage, and integrated these three aspects to construct an overall pattern for evaluating transportation development [2]. Since then, an increasing number of scholars have studied the traffic dominance from different scales. For example, Sun Hongri studied the traffic dominance degree in Northeast China from the perspective of large regions, and believed that the main traffic lines make the regional development polarized, and the rapid transportation mode contributes greatly to the traffic dominance degree in the Northeast region [3]; Xue-gang Cui and Wei Wu studied the traffic dominance from the perspective of urban agglomerations and showed that central cities generally have high traffic dominance and drive the traffic dominance of neighboring cities [4-5]. Meng Deyou and Peng Xiangming studied the intra-regional traffic dominance from county-level regions, and the study showed that the districts and counties near the high-speed transportation network have higher traffic dominance, and the economic development level of districts and counties with high traffic dominance is also high, showing a higher coupling degree [6-7]. From the existing studies, most scholars study the transportation dominance from the large regional scale, while less studies are conducted on the transportation dominance within mega-cities. Compared with the monotony of cross-regional transportation networks, the internal transportation networks of mega-cities are richer, and a variety of transportation options are available for people and materials to enter and exit. Whether the traffic dominance degree still has cross-regional characteristics under the diverse traffic network will be the direction that this paper attempts to explore.

As an important carrier of human social production activities, land is the undertaker of all social development. As a limited resource, the rational and efficient use of land is always an important proposition for human development. Land use efficiency (LUE) is an indicator reflecting the rational degree of land use, which refers to the ability to obtain the maximum output with the minimum input under certain social and natural conditions [8]. It is of great practical significance to carry out land use efficiency research to optimize urban land spatial allocation, promote intensive land use and change the development mode of economic development. How to evaluate the land use efficiency scientifically and effectively is the focus of many scholars at present. Relevant studies have shown that urban area heterogeneity and urban scale can significantly influence LUE, and urban form characterized by high-density patches is beneficial to the improvement of LUE in large cities, but not in small cities [9].Regional economic integration improves urban land use efficiency through the flow of market factors and redistribution of industrial structures [10-11]. In urban agglomerations based on transportation interconnection, the overall land use efficiency is improved through industrial integration, factor flow, and division of labor and cooperation [12]. In terms of research methods, stochastic frontier analysis (SFA) [13-14] and data envelopment analysis (DEA) [15] are two completely different efficiency analysis methods that have been gradually applied to land use efficiency evaluation. SFA obtains efficiency values by accurately constructing the production frontier surface, which can separate technical inefficiency from random error [16], with the disadvantage that the systematic error introduced by the functional form will be included in the inefficiency term [17]. The DEA method does not need to pre-determine the weights, the operation is simple and can effectively avoid the systematic errors caused by the function form setting [18]. The three-stage DEA model, however, incorporates the SFA model into the DEA model [19], which effectively addresses the shortcomings of the above methods and is widely used in the industrial energy sector and banking sector [20-21]. In addition, with the rapid socioeconomic development, the scale of urban land occupation is expanding, and the relationship between transportation and land use efficiency has received more attention. The study showed that there is a significant correlation between transportation development and land use efficiency [22]. Urban transportation networks drive urban land policy changes, land use intensity, and real estate prices that effect land use efficiency [23], and a well-developed transportation road network causes spatial spillover effects on land use efficiency [24].

In exploring the relationship between transportation dominance and land use efficiency in Shanghai, this paper focuses more on land output efficiency and tries to evaluate which areas in Shanghai can achieve higher economic output as well as lower undesirable output with limited land supply. To this end, the super-efficiency SBM model with bad output is used as the calculation method of land use efficiency, and the output data is adjusted by the three-stage DEA model, so as to obtain a better evaluation effect of land use efficiency. Quantitative calculation of the coupling coordination degree between traffic dominance and land use efficiency in each district of Shanghai, to explore the interaction between traffic and land use efficiency in megacities.

2. Data source and processing

2.1 Overview of the study area

Located in eastern China, Shanghai is situated at the mouth of the Yangtze River and is the core region of the Yangtze River Delta. As a pilot city of national innovation and reform, Shanghai has high economic vitality and development momentum. At the same time, Shanghai's development is inseparable from the supply of resources from neighboring provinces and cities, and its well-developed transportation network provides an efficient channel for the contact of people and materials. As a mega-city in the eastern region, Shanghai has both long-developed central urban areas and newly developed peripheral suburban areas, with different emphasis on the development of primary, secondary and tertiary industries in each district, and is a suitable area to study the relationship between transportation and urban land use efficiency within a mega-city because of the close distance between the regions, various modes of transportation and frequent internal exchanges.

2.2 Data sources

With 2019 as the research time node, combined with the selected indicators, the district as the research unit, statistical data mainly from the district statistical yearbook, statistical bulletin and Shanghai ecological environment bulletin, etc., the traffic data mainly from the 2019 Shanghai map, Gao De map, etc., the specific data sources are shown in Table 1.

Table 1 Data sources

Level 1 indicators	Level 2 indicators	Data source
Land input	Number of people employed in secondary and tertiary industries	Shanghai Fourth Economic Census Bulletin
	Fixed asset investment amount Construction land area	Statistical yearbook and statistical bulletin of each district
Expected output of land	Secondary industry added value Tertiary industry added value Export amount	Statistical yearbook and statistical bulletin of each district
Undesired output of land	Daily average PM2.5 concentration Daily average NO_2 concentration Daily average SO_2 concentration	Shanghai Ecological Environment Bulletin
Three-stage model environment variables	Road network density	Shanghai Map 2019, 6th Edition (Review Number: GS (2013) 2558)
	Resident Population Density Share of tertiary sector in GDP	Statistical yearbook and statistical bulletin of each district
Road density	Highways	Shanghai Map 2019, 6th Edition (Review Number: GS (2013) 2558)
	national highway	Shanghai Map 2019, 6th Edition (Review Number: GS (2013) 2559)
	Expressways	Shanghai Map 2019, 6th Edition (Review Number: GS (2013) 2560)
	Provincial roads	Shanghai Map 2019, 6th Edition (Review Number: GS (2013) 2561)
Number of hubs	High Speed Toll Stations	Shanghai Road Traffic and Transportation Administration official website
	Metro Station	Shanghai Metro Official Website
	Large train stations	Baidu
	Large civil airport	Baidu
Accessibility	Passage time	Gao De Map API

2.3 Data processing

The spatial distribution data of expressways, national roads, expressways and provincial roads in Shanghai in 2019 were obtained by numerical processing, and the corresponding weights were assigned to expressways, national roads, expressways and provincial roads according to different traffic levels, i.e., 1.2, 1.1, 1.0 and 0.9, respectively, and the traffic network density of each district in Shanghai was calculated according to different traffic levels and weighting of weights, and the extreme difference standardization method was applied to them The traffic network density index data is obtained by standardizing the data with the extreme difference standardization method.

The traffic artery impact degree data were evaluated by means of value scoring. Considering that railroads, subways, highways, and airports are open to society through their stations, only the stations are counted in the data processing. Subway stations and expressway toll stations are assigned values according to the number of stations they have; interchange stations, outbound interchange stations and outbound transfer stations in the subway network are regarded as the same station; subway stations on the border are counted in both districts; Jinshan Railway is regarded as the rail transit ("subway") in Jinshan District; the entrance and exit of expressway toll stations are The airport and railway station are statistically assigned according to the distance from the district government location to the nearest airport railway station, mainly including Shanghai Hongqiao International Airport and Shanghai Pudong International Airport and four passenger railway stations of Shanghai Hongqiao Railway Station, Shanghai Station, Shanghai South Railway Station and Shanghai West Railway Station, as shown in Table 2, and the impact degree of traffic arteries in each district is calculated according to the assigned values and stations, and the evaluation statistics are Standardized processing.

Table 2 Traffic Hub Statistics Methodology

Hubs	Scoring Rules	Scoring	Hubs	Scoring Rules	Scoring
Train stations	Large train station available	2	High Speed Toll Stations	Number of toll stations 26-50	2
	Distance to major train stations 1-25 km	1.5		Number of toll stations 1-25	1.5
	Distance to major train stations 25-50 km	1		No toll station	1
Airports	Large civilian airport available	2	Rail Transit	More than 100 sites	2
	Distance to large civil airport 1-25 km	1.5		Number of stations 51-100	1.5
	Distance to large civil airport 25-50 km	1		Number of stations 26-50	1
				Number of stations 1-25	0.5
				No stations	0

Location advantage degree data in this paper is obtained by considering the convenience of people and materials entering and leaving Shanghai in each district of Shanghai. For the people to enter and leave Shanghai in the city mainly choose to travel by car, data processing in each district evenly selected five points as the starting point, selected Shanghai's two major international airports, four railway stations, eight high-speed exit toll station as the destination point. The same five points in each district are selected as departure points, while Yang Shan Deepwater Port and Wai Si Terminal are added as destination points. Based on the time convolutional network (TCN) model, the passage time of different road sections is predicted by combining historical information and road attributes, and the passage time is obtained by calling Gao De Map API using Python, and the district dominance degree is obtained statistically and standardized, and the relevant destination names and weights are shown in Table 3.

Based on the above obtained standardized values of traffic network density, traffic artery influence degree and location advantage degree of each district, the summation calculation is used to obtain the comprehensive traffic advantage degree of each district, which is a good data guideline for the subsequent content research.

Table 3 Destination names and calculation weights

People driving destinations	Weight	Cargo driving destinations	Weight
Shanghai Hongqiao International Airport	1	Shanghai Hongqiao International Airport	0.1
Shanghai Pudong International Airport		Shanghai Pudong International Airport	
Shanghai South Railway Station		Shanghai South Railway Station	0.1
Shanghai Hongqiao Station		Shanghai Hongqiao Station	
Shanghai Station		Shanghai Station	
Shanghai West Station		Shanghai West Station	
Qidong South Tollbooth		Qidong South Tollbooth	0.7
Taicang Toll Station		Taicang Toll Station	
Lujia Toll Station		Lujia Toll Station	
Qiandeng Toll Station		Qiandeng Toll Station	
Jinze Toll Station		Jinze Toll Station	
Zhufeng Highway Tollbooth		Zhufeng Highway Tollbooth	
Jiashan Toll Station		Jiashan Toll Station	
Xincang (Dushan Port East) Toll Station		Xincang (Dushan Port East) Toll Station	
		Yangshan Deepwater Port	0.1
		Wai Si Pier	

3. Research methodology

3.1 Selection of land use efficiency indicators

Combined with the current existing research results, data availability and the requirements of the number of model indicators, representative land use efficiency evaluation indicators are selected, among which the input indicators select the number of employees in the secondary and tertiary industries, the amount of fixed asset investment and the construction land area; Expected output selects the added value of the secondary industry, the added value of the tertiary industry and the export value; Undesirable outputs selected daily average PM2.5 concentration, daily average NO_2 concentration and daily average SO_2 concentration; Environmental variables select the density of the road network, the density of the permanent population, and the proportion of the tertiary industry in GDP.

3.2 Three-stage Super-SBM model

3.2.1 Phase 1 - Preliminary calculation of efficiency values

The first stage adopts the Super-SBM model with undesirable outputs, which is output-oriented and preliminarily calculates the efficiency value, and the Super-SBM model is calculated as follows:

$$\min \rho = \frac{1+\frac{1}{m}\sum_{i=1}^{m} S_i^- / x_{ik}}{1-\frac{1}{q_1+q_2}(\sum_{r=1}^{q_1} S_r^+ / y_{rk} + \sum_{t=1}^{q_2} S_t^{b-} / b_{rk})}$$

$$s.t. \sum_{j=1, j\neq k}^{n} x_{ij}\lambda_j - s_i^- \le x_{ik}$$

$$\sum_{j=1, j\neq k}^{n} y_{rj}\lambda_j + s_r^+ \ge y_{rk} \qquad (1)$$

$$\sum_{j=1, j\neq k}^{n} b_{tj}\lambda_j - s_t^{b-} \le b_{tk}$$

$$1-\frac{1}{q_1+q_2}(\sum_{r=1}^{q_1} S_r^+ / y_{rk} + \sum_{t=1}^{q_2} S_t^{b-} / b_{rk}) > 0$$

$$\lambda, s^-, s^+ \ge 0$$

$$i = 1,2,\ldots,m; r = 1,2,\ldots,q; j = 1,2,\ldots,n(j \neq k)$$

where λ is the linear combinatorial coefficient of the DMU, m is the number of inputs, q is the number of outputs, n is the number of DMU, and s_r^+, s_r^-, s_t^{b-} represents the relaxation variables of input, desired output, and undesirable output, respectively.

In this paper, MaxDEA software is used to calculate the overall efficiency of the evaluation unit. Considering that the number of indicators selected by the DEA model cannot exceed half of the number of evaluation units, the three index values of the undesirable output of the daily average PM2.5 concentration, the daily average NO_2 concentration and the daily average SO_2 concentration of the undesirable output are combined as the comprehensive undesirable output.

3.2.2 Phase II - Adjustment of outputs

Combined with the two adjustment formula schemes in the literature [20], considering the specific situation studied in this paper, one of the adjustment formulas was selected for output adjustment. For the mth desired output formula is calculated as follows:

$$\begin{aligned} & S_i^m = f^m + V_i^m + U_i^m = \alpha_i^m + \beta^{m'}\lambda_i + V_i^m + U_i^m \\ & V_i^m \sim N(0, \delta_{vm}^2) \\ & U_i^m = |U_i^m| \\ & U_i^m \sim N(0, \delta_{um}^2) \perp V_i^m \end{aligned} \qquad (2)$$

where S_i^m is the first stage of relaxation expected to produce the first DMU. f^m represents the influence of environmental factors on the relaxation of the first stage, λ is the element of the environmental variable, $\beta^{m'}$ is the amount of parameters to be estimated, and α_i^m measures the heterogeneity of DMUs. $V_i^m + U_i^m$ is a mixed error term, V_i^m represents random noise effects, and U_i^m represents management inefficiency.

The formula for the j th undesirable output is as follows:

$$\begin{aligned} & S_i^j = f^j + V_i^j + U_i^j = \alpha_i^j + \beta^{j'}\lambda_i + V_i^j + U_i^j \\ & V_i^j \sim N(0, \delta_{vj}^2) \\ & U_i^j = |U_i^j| \\ & U_i^j \sim N(0, \delta_{uj}^2) \perp V_i^j \end{aligned} \qquad (3)$$

where S_i^j is a stage of relaxation of the j th unintended output of the i th DMU. The parameter α_i^j, $\beta^{j'}$, V_i^j, U_i^j are adjusted with respect to α_i^m, $\beta^{m'}$, V_i^m, U_i^m, references in Equation (2), using the following formula:

$$(y_k^m)^A = y_k^m + \left[\hat{f}_k^m - \min_i \hat{f}_i^m\right] + \left[\hat{v}_k^m - \min_i \hat{v}_i^m\right] = y_k^m + \left[\left(\alpha_k^m + \beta^{m'}\lambda_k\right) - \min_i\left(\alpha_i^m + \beta^{m'}\lambda_i\right)\right] + \left[\hat{v}_k^m - \min_i \hat{v}_i^m\right] \quad (4)$$

$$(b_k^j)^A = b_k^j - \left[\hat{f}_k^j - \min_i \hat{f}_i^j\right] - \left[\hat{v}_k^j - \min_i \hat{v}_i^j\right] = b_k^j - \left[\left(\alpha_k^j + \beta^{j'}\lambda_k\right) - \min_i\left(\alpha_i^j + \beta^{j'}\lambda_i\right)\right] + \left[\hat{v}_k^j - \min_i \hat{v}_i^j\right] \quad (5)$$

$$i = 1, \ldots, k$$

where y_k^m and $(y_k^m)^A$ are the pre- and post-adjusted values of the m th expected output k th DMU. b_k^j and $(b_k^j)^A$ are the adjusted pre- and post-adjusted values of the k th DMU of the j th undesirable output.

3.2.3 Phase 3 - Recalculation of efficiency values

The adjusted output data and input data are recalculated using the Super-SBM model containing undesirable outputs for efficiency value calculation, and the overall efficiency of the evaluation unit is obtained by being output-oriented.

3.3 Coupled coordination degree model

Coupling degree is a physical concept that refers to the phenomenon in which two or more systems affect each other through various interactions between themselves and the outside world. In this paper, the relationship between traffic advantage degree and land use efficiency is expressed through the coupling coordination degree model, and the coupling degree calculation formula is as follows:

$$C = 2\sqrt{f(u)g(e)} / (f(u) + g(e)) \quad (6)$$

Among them, $f(u)$ and $g(e)$ represent transportation advantage and land use efficiency, respectively. The closer C is to 1, the higher the coupling between the two. The degree of coupling can be used to describe the degree of interaction or influence between systems, but it is impossible to achieve the level of coordination of coupling between the two, so it is necessary to further construct the coupling coordination model of the two, that is:

$$D = \sqrt{CT}, T = \alpha f(u) + \beta g(e) \quad (7)$$

Among them, C is the coupling degree, D is the coupling and coordination degree of transportation advantage degree and land use efficiency, T is the comprehensive harmonization index, and the parameters α and β represent the contribution degree of transportation advantage degree and land use efficiency, considering the same degree of influence between the two, the value taken in this article is 0.5. Referring to the related literature [25], the coupling coordination degree of traffic advantage and land use efficiency is divided into four levels, which 0≤D<0.3 is low coupling coordination, 0.3≤D<0.5 is lower coupling coordination, 0.5≤D<0.8 is higher coupling coordination, and 0.8≤D≤1 is high coupling coordination.

4. Result Analysis

4.1 Traffic advantage analysis

Based on the standardized results of traffic network density, traffic trunk line influence degree and location advantage degree obtained by data processing, the traffic advantage degree of each district is obtained by adding and summing. The results are shown in Table 4.

Table 4 Traffic advantages of districts in Shanghai

Region	Traffic network density	Influence degree of traffic	Location advantage	Traffic advantage

		trunk line		
Changning District	0.853	0.375	0.988	2.216
	1.000	0.250	0.883	2.133
Hongkou District	0.600	0.500	1.000	2.100
	0.934	0.250	0.885	2.069
Putuo District	0.730	0.375	0.878	1.983
	0.284	0.750	0.828	1.862
Huangpu District	0.412	0.500	0.891	1.803
	0.324	0.500	0.755	1.579
Jing'an District	0.225	1.000	0.345	1.570
	0.542	0.250	0.758	1.550
Minhang District	0.196	0.500	0.808	1.504
	0.170	0.500	0.789	1.459
Xuhui District	0.261	0.375	0.693	1.329
	0.164	0.250	0.463	0.877
Jiading District	0.095	0.250	0.388	0.733
	0.000	0.000	0.000	0.000

The traffic dominance of each area is divided into five categories by using the natural breakpoint method in GIS software for result display, as shown in Figure 1. Class I areas (with a traffic advantage of 1.984-2.216) are distributed in the central urban area, including Changning District, Hongkou District, Putuo District and Huangpu District, which belong to the most densely populated areas in Shanghai. The spatial distance from these areas to any exit direction of Shanghai is roughly the same. Class II areas (with a traffic advantage of 1.580-1.983), including Jing'an District and Xuhui District in the central urban area and Minhang District in the suburban area. Minhang District has the best traffic conditions outside the central area. Class III areas (with a traffic advantage of 0.878-1.579) are Jiading District, Pudong New Area, Yangpu District, Songjiang District, Qingpu District and Baoshan District, which are mainly distributed around the central urban area, of which Yangpu District is the area with the lowest traffic advantage in the central urban area. Class IV areas (traffic dominance between 0.001-0.877), only Jinshan District and Fengxian District, located in the south of Shanghai, belong to areas with relatively weak infrastructure construction and slow traffic development. Class V area (traffic advantage degree is 0), only Chongming district is located in the north of Shanghai, far from the central urban area, and the traffic network is single. Since the three traffic advantage indexes of Chongming district are the smallest and the index values after standardized treatment are 0, the traffic advantage degree is 0, indicating that the traffic advantage degree in Shanghai is relatively low.

From the perspective of space, the traffic advantage of Shanghai presents an obvious circle structure. The advantages of central urban areas are obvious, while the advantages of peripheral areas are reduced. Hongkou District, Jing'an District, Huangpu District, Putuo District, Changning District, Xuhui District and Minhang

District are in the first echelon of traffic advantage (class I and II areas). Although these areas lack expressways and national roads, they have developed subway, urban expressway, provincial road and trunk road networks, At the same time, most of these districts have a small administrative area, which makes the road network density relatively large. Moreover, Shanghai Hongqiao International Airport, Shanghai Hongqiao Station, Shanghai railway station, Shanghai South Railway Station and Shanghai West Railway Station are all located within the administrative scope of these districts, with strong foreign exchange ability; In addition, because it is located in the central area of Shanghai, there is no obvious long-distance traffic time when driving to each exit Expressway in the urban area, and the comprehensive traffic access time is short. Songjiang District, Qingpu District, Jiading District, Baoshan District, Yangpu District and Pudong New Area are in the second echelon (Class III areas). These districts are distributed in the central area, with developed expressways, national roads and provincial roads. The administrative area is large, the road network density is small, and the traffic time to reach the eight Expressway exits shows obvious polarization, As a result, the traffic advantage is not as good as that of the central urban area; Thanks to the radiation influence of the transportation network in the central urban area, the second echelon area has a convenient personnel exchange channel inward and an efficient logistics and transportation network outward. Jinshan District, Fengxian District and Chongming district are ranked in the third echelon (class IV and V areas), with relatively single transportation mode, low impact score of transportation trunk lines and poor traffic accessibility.

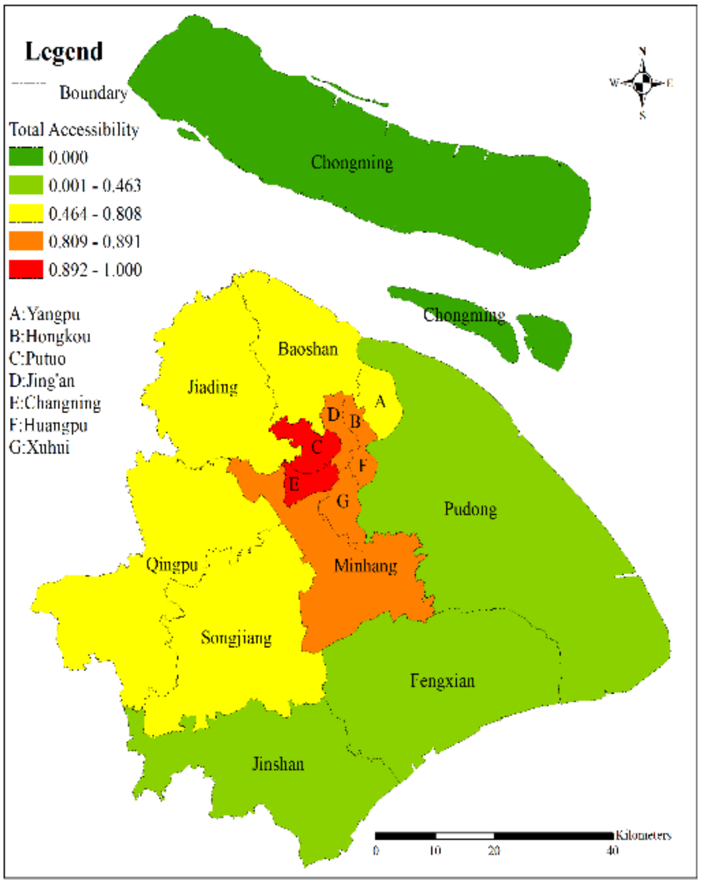

Figure 1 Distribution of traffic dominance in Shanghai

4.2 Analysis of land use efficiency

MaxDEA software is used to calculate the land use efficiency of each district in Shanghai. The value of land use efficiency in the first stage of each district is listed in Table 5. Without removing the influence of statistical errors and environmental factors, the comprehensive efficiency value after using the super efficiency model has reached the efficiency frontier in 6 areas, and Pudong New Area has reached 2.426. In the central urban area, only Yangpu District and Huangpu District are at the forefront of efficiency, and the efficiency value of other districts is low, only about 0.5. The comprehensive efficiency of Songjiang District, Jinshan District and Jiading District in the suburbs is higher than 1, that of Qingpu District and Fengxian District is between 0.5-0.6, and that of Baoshan District and Chongming district is the lowest.

Table 5 Land use efficiency in the first stage

Region	Efficiency value	Region	Efficiency value	Region	Efficiency value	Region	Efficiency value
Changning District	0.488	Qingpu District	0.530	Jinshan District	1.033	Fengxian District	0.606
Yangpu District	1.206	Putuo District	0.430	Jiading District	1.141	Chongming District	0.310
Xuhui District	0.682	Minhang District	0.607	Huangpu District	1.241	Pudong New Area	2.426
Songjiang District	1.019	Jing'an District	0.509	Hongkou District	0.518	Baoshan District	0.380

Further use frontier 4.1 software for the second stage regression analysis. The road network density, population density and the proportion of tertiary industry in GDP are selected as explanatory variables to regress the output relaxation variables. The results are shown in Table 6. The numerical and test results show that the selection of the model is reasonable, and the coefficient is negative, indicating that the land use efficiency is promoted by the external environmental variables. Large external environmental variables can increase the original value of output, so as to reduce relaxation and improve land use efficiency; A positive coefficient indicates that land use efficiency is hindered by external environmental variables. The increase of external environmental variables will reduce the original value of output, increase relaxation and reduce land use efficiency. The results show that the proportion of the tertiary industry in GDP hinders the growth of the added value of the secondary industry, but significantly promotes the added value, export volume and comprehensive bad output of the tertiary industry; Population density and road network density have no significant impact on the added value of the tertiary industry; For the calculation results after formula adjustment, the impact of random error is weak, which is mainly reflected in the impact of environmental variables on the evaluation unit.

Table 6 Results of regression analysis in the second stage

	Added value of secondary industry		Added value of tertiary industry	
	Coefficient	T value	Coefficient	T value
Constant	2.14E+02	2.14E+02***	5.59E+03	8.84E+01***
Road network density	-4.78E-01	-3.37E+00***	8.14E-02	2.44E-01
Population density	2.62E+02	2.62E+02***	4.19E+01	1.03E-01
Proportion of tertiary industry in GDP	2.92E+02	2.92E+02***	-5.29E+03	-7.86E+01***
Sigma-squared	4.69E+05	4.69E+05***	1.28E+07	1.28E+07***
Gamma	1.00E+00	4.84E+04***	1.00E+00	1.21E+05***
Log likelihood	-1.14E+02		-1.42E+02	
LR	1.06E+01***		9.10E+00**	
	Export volume		Comprehensive bad output	
	Coefficient	T value	Coefficient	T value
Constant	3.60E+03	2.34E+02***	2.39E+01	6.15E+00***
Road network density	-9.24E-01	-3.71E+01***	-2.48E-02	-4.64E+00***
Population density	9.33E+02	5.58E+02***	1.46E+01	4.13E+00***
Proportion of tertiary industry in GDP	-3.85E+03	-4.26E+02***	-2.17E+01	-2.17E+00***
Sigma-squared	6.33E+06	6.33E+06***	1.13E+03	1.15E+03***
Gamma	1.00E+00	6.93E+05***	1.00E+00	1.05E+05***
Log likelihood	-1.35E+02		-6.96E+01	
LR	1.12E+01***		6.07E+00*	

Note: * significance is more than 10%, * * significance is more than 5%, * * * significance is more than 1%.

The output is adjusted through the results of the second stage regression analysis, and the efficiency is calculated again by using maxdea software. The results are shown in Table 7. After the third stage treatment, the comprehensive land use efficiency of 8 districts is at the forefront of efficiency, of which 3 are located in the downtown area and 5 in the suburbs; The comprehensive efficiency of Songjiang District, Jing'an District, Xuhui District and Minhang District is between 0.6-0.8, which belongs to a good level; The comprehensive efficiency values of Putuo District, Qingpu District and Baoshan district are between 0.5-0.6, belonging to the medium level; Changning District has the lowest land use efficiency. From the perspective of space, the eastern region should be significantly better than the western region, which is consistent with the Shanghai development strategy to set Pudong New Area as a leading area for innovative development. As a newly developed urban area in recent 30 years, Pudong New Area has significantly higher economic vitality than other areas; In addition, the urban areas along the Huangpu River also have good land use efficiency. From the perspective of non-performing production, the original statistics show that the PM2.5 in the western urban area and SO_2 is high, and the concentration of NO_2 in the central urban area is high. The total bad output after three-stage adjustment is also high in the western urban area and the central urban area. Compared with the comprehensive efficiency of land use, it is found that the bad output reduces the land use efficiency of each district; Therefore, in the case of equal input and expected output, reducing bad output can improve land use efficiency, which is also in line with the connotation of coordinated development of city and ecological environment.

Table 7 Land use efficiency after treatment in the third stage

Region	Efficiency value	Region	Efficiency value	Region	Efficiency value	Region	Efficiency value
Changning District	0.313	Qingpu District	0.577	Jinshan District	1.163	Fengxian District	1.008
Yangpu District	1.562	Putuo District	0.579	Jiading District	1.027	Chongming District	1.036
Xuhui District	0.756	Minhang District	0.678	Huangpu District	1.367	Pudong New Area	1.529
Songjiang District	0.785	Jing'an District	0.760	Hongkou District	1.037	Baoshan District	0.555

Comparing the comprehensive efficiency values of the first and third stages (Fig. 2), it is found that the comprehensive land use efficiency of 12 districts has been improved, and Chongming district has increased the most, reaching 0.726; The comprehensive land use efficiency of the four districts decreased, and the efficiency value of Pudong New Area decreased the most, reaching 0.897; Environmental factors have greatly adjusted Hongkou District, Fengxian District, Chongming district and Pudong New Area; The results of SFA show that the higher proportion of tertiary industry in GDP brings additional output to Pudong New Area, while the relatively low proportion of tertiary industry in GDP brings output inhibition to Hongkou District, Fengxian District and Chongming district.

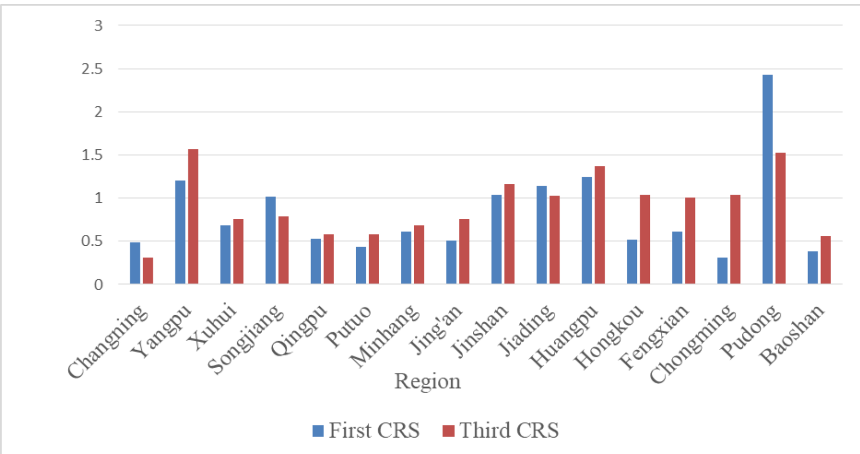

Figure 2 Comparison of land use efficiency values between the first stage and the third stage

4.3 Coupling coordination degree analysis

The coupling coordination degree model was used to measure the coupling degree (C) and coupling coordination degree (D) of traffic dominance and land use efficiency of each district in Shanghai (Figure 3). In terms of coupling degree, except for Changning District and Chongming District, the coupling degree values of all other districts are above 0.7, which is a high coupling degree, indicating that there is a high correlation between traffic dominance and land use efficiency. In terms of coupling coordination degree, except for Chongming District and Changning District, which have small coupling coordination degree values and belong to low coupling coordination degree type, the coupling coordination degree values of all other districts are above 0.5; Huangpu District, Yangpu District and Pudong New District in the eastern region belong to high coupling coordination degree type, which indicates that the land use mode and transportation development are in good mutual promotion, and the developed and fast transportation system promotes the land use efficiency. The coupling coordination degree of the remaining districts is of higher coupling coordination degree type.

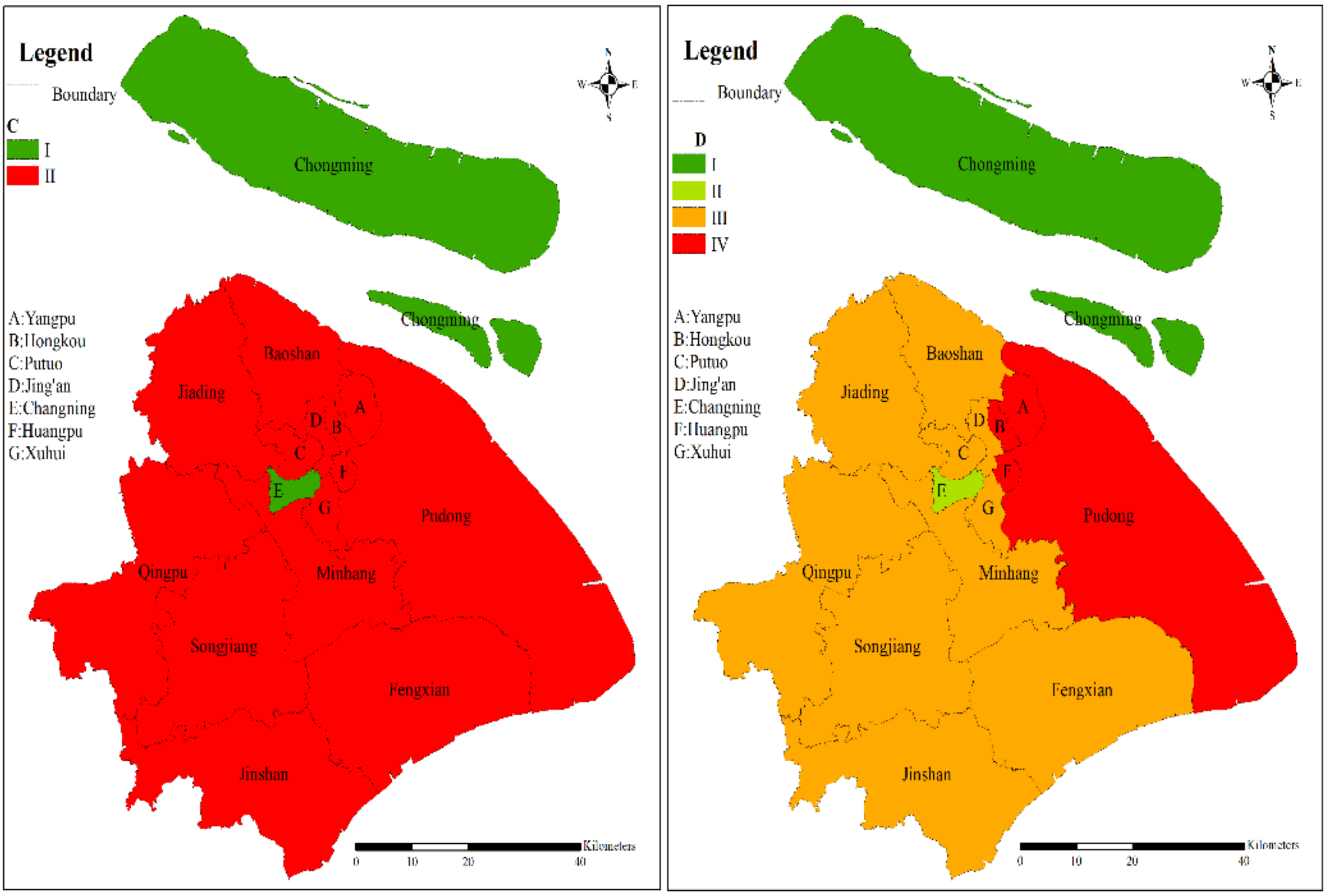

Figure 3 Coupling degree and coupling coordination degree

Specifically (Figure 4), Huangpu District, Yangpu District, Pudong New Area and Hongkou District belong to high traffic advantage and high land use efficiency, where traffic access and land use complement each other and regional development reaches a coordinated state; Jing'an District, Minhang District and Xuhui District belong to high traffic advantage and medium land use efficiency, where the maximum efficiency of land use has not yet been reached and the development dividend brought by traffic needs to be further explored. Putuo District belongs to high traffic advantage degree low land use efficiency, land use has output deficiency, need to further optimize land input, enhance innovative development momentum; Changning District belongs to high traffic advantage degree poor land use efficiency, land output has serious deficiency, need to optimize land use mode, increase land output capacity; Jiading District belongs to medium traffic advantage degree high land use efficiency, the capacity of land output reaches The efficiency frontier, transportation development lags behind land development and utilization; Songjiang District belongs to medium transportation advantage degree medium land use efficiency, and the coupling coordination degree does not reach the highest, indicating that transportation development and land development are in a state of mutual friction, and the two need to coordinate and synchronize development; Qingpu District and Baoshan District belong to medium transportation advantage degree low land use efficiency, the coupling coordination degree is not high, and they are in the intermediate stage of development, in Jinshan District and Fengxian District are of low traffic advantage and high land use efficiency, benefiting from high tertiary industry output and having strong economic vitality under the condition of single traffic mode; Chongming District is of poor traffic advantage and high land use efficiency, with single traffic mode and low land output, benefiting from low land Input and poor output, Chongming District transportation and land development and utilization are both at the primary level, both still have a large development potential space.

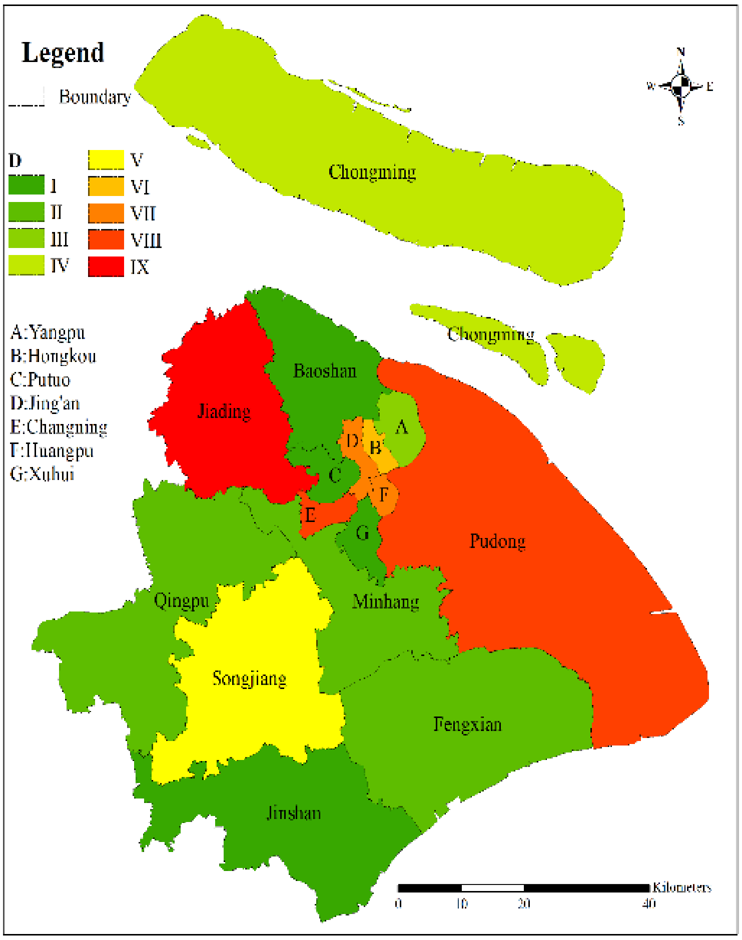

Figure 4 Degree of coupled coordination between traffic dominance and land use efficiency

5. Conclusions and Recommendations

In this paper, the traffic dominance model and the three-stage Super-SBM model were used to study the traffic development, land use efficiency and the interaction between them in 16 districts of Shanghai, and the following conclusions were obtained.

(1) In terms of traffic dominance, the traffic dominance of each district in Shanghai shows an obvious circle structure, with high traffic dominance in the central city and low traffic dominance in the peripheral areas. The central city and Minhang District have dense transportation networks and major transportation hubs, and are the best transportation development areas in Shanghai; Songjiang District, Qingpu District, Jiading District, Baoshan District, Yangpu District and Pudong New District have slightly lower transportation dominance and are in the second echelon of transportation development in Shanghai; Jinshan District, Fengxian District and Chongming District have the lowest transportation dominance and still need to continuously strengthen the construction of transportation infrastructure.

(2) In terms of land use efficiency, calculated by the three-stage Super-SBM model, the land use efficiency of each district in Shanghai shows that the eastern region is higher than the western region, and the comprehensive land use efficiency of Yangpu District, Pudong New Area, Huangpu District, Jinshan District, Hongkou District, Chongming District, Jiading District and Fengxian District reaches the efficiency frontier; Songjiang District, Jing'an District, Xuhui District and Minhang District have a high level of land use efficiency; Putuo District, Qingpu District and Baoshan District have a medium level of land use efficiency; Changning District shows a low level of land use efficiency.

(1) Traffic development and land use in most urban areas are in a coordinated development, and traffic and land development and utilization are complementary to each other. Huangpu District, Yangpu District, Pudong New Area and Hongkou District belong to high coupling coordination degree, and land development and utilization and transportation development present a mutual promotion role and a good development pattern; Chongming District and Changning District belong to low coupling degree, and need to accelerate to make up for the shortcomings and improve land use capacity; the remaining districts belong to higher coupling coordination status, and need to further explore the urban development path and optimize the urban development pattern, so that transportation and land The rest of the districts belong to a high coupling coordination state, and need to further explore the urban development path, optimize the urban development mode, and make the transportation and land use coordinate and improve.

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