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Research Article

Determining Sustainable Land Use by Modal Split Shift Strategy for Low Emissions: Evidence from Medium-Sized Cities of China

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The rapid urbanization in medium-sized cities in China has led to revolution of transportation systems resulting in negative impacts on the environment. Evaluating the relationship among land use, modal split, and traffic emission can help propose regional optimal land use pattern by modal shift strategy to reduce carbon emissions. Data were collected from seven medium-sized cities in China. The study first evaluated the land use that influences mode split and the relationship between modal split and traffic emission. Then a sustainable mode shift strategy was provided to reduce emissions. Lastly, we provided constructive suggestions for sustainable land use pattern by mode shift strategy. To reduce emission per trip, nonmotorized trip modes and public transit should be increased, and, accordingly, the residence-industry and residence-retain mix entropy should be increased. The study found that the regions with job-housing balance or retail-housing mix could increase the mode share of nonmotorized vehicle traffic and reduce car use. The modal shift can in the future benefit emission reductions.

1. Introduction

In the past, a traditional perspective is that increasing the road supply can fit the increasing need of traffic demand. However, in recent years, the perspective is not appropriate anymore. The current interest focuses on the management of traffic demand and improve the development of public transit and other slow traffic trip modes. Considering the fact that there is a close relationship between land use and traffic demand, the study that evaluates the impacts of land use changes on travel behaviours has drawn great interests by researchers around the world.

Over the past decade several papers have presented overviews of studies in the area of the impacts of land use on travel behaviour. Much country-specific empirical research is conducted in the United States [1–7], in the UK [8], in Holland [9, 10], in Hong Kong [11], and in Taiwan [12]. In China, some researches are conducted in the megacities in recent years [13–15]. The overviews show that the above-mentioned determinants dominate the research. In above research, urban form is characterized using the parameters such as the population or employment density, land use mix, distance to facilities for shopping, accessibility, street connectivity, transit accessibility, and roadway design. But travel dependent variables are often automobile use (expressed in kilometres), total travel distances, and modal split variables. However, previous studies only offer contradictory results. And they are unable to account for the reliably of the relationship between urban form and travel behaviour [16].

Despite the significant accumulation of empirical evidence regarding the relationships between urban form and travel demand, many issues focus on exploring the correlation between urban form and travel behaviour. They did not evaluate how urban form should develop and change based on optimal travel behaviour. This issue should be studied particularly. An important related issue is how to guide the urban development by shift modal split for reducing the traffic emission. Most previous studies applied single regression equation based methods that could not clearly represent sustainable urban form by mode choice optimization for low emission. To clarify the complex relationships between urban form and travel demand and present the sustainable urban

form for reducing traffic emission, this study employed the data collected at seven medium-sized cities selected in the Yangtze River Delta (YRD) economy district of China.

In year 2009 the GDP in China has reached up to 33,535 billion RMB. In the past ten years, the GDP had rapidly increased by 10% per year which results in the development of urban form and extention of land area. As a result, the characteristics of travel activities have changed greatly. The environment was affected by the increased motorized travel demand. To reduce city emission and promote city sustainable development, it is necessary to develop low carbon modal shift strategies and propose sustainable urban form in China, based on the analysis of relationship between urban form and travel behaviour.

The study chooses Yangtze River Delta economy district as the research objective. The Yangtze River Delta economy district locates within the southeast of China, including Shanghai, Jiangsu, Zhejiang, and parts of Anhui. The total area of YRD region is about 354,400 square kilometers. The district is associated with high economic levels and is the rapidly developed area in China. In year 2007 the urbanization level is above 70% which is 24.3% higher than the average level in China. And the cities with population of 0.5–1 million occupy over 70% of all cities. Considering that, this study selected seven typical medium-sized cities within the district as the research objective. The study tries to analyze how the land use affects the modal choices and propose sustainable land use pattern based on low carbon modal shift strategies.

The primary objective of this study is to develop a sustainable urban form strategy for medium-sized cities in China. More specifically, this study includes three major tasks. Firstly, the degree of association between the land use and modal split in those cites is explored. The land use patterns such as residential density and land use balance were qualified. Secondly, the relationship between the modal split and traffic emission is clarified. A sustainable modal shift strategy by different purposes for reducing emission in those cities is provided. Finally, the sustainable land use pattern by modal shift strategy for medium-sized cities in China is proposed.

2. Data and Method

2.1. Data Source and Collection. The seven cities (see Figure 1) selected as research objective in the study include Xuzhou which locates at northern Jiangsu with a poor financial situation and a population of 950,000; Changshu which is a famous tourism city with a population of 550,000; Nantong which locates at eastern Jiangsu with a population of 647,000; Wenling which locates at southern part with good economic situation and a population of 970,000; Tongling which locates at central-southern Anhui with a population of 590,000; Suzhou which locates at southern Jiangsu with a good economic situation and a population of 1,250,000; and Kunshan which locates next to Shang with a good economic situation and a population of 510,000. The population within those cities ranges from 0.5 to 1.3 million. The land use pattern and the travel features are quite different among those cities.

The data was collected to discuss the relationship between land use pattern and travel activities. The land use data were from the materials of the overall city planning projects. Over 1000 traffic analysis zones (TAZ) are divided into the seven cities based on the geographical information systems. In each TAZ, the land use variables, such as density and land use balance, were computed. The travel activity data were extracted from the residence travel survey database which were conducted during the comprehensive transportation planning during the period of 2000–2004. Based on these comprehensive travel databases, the travel behaviour can be extracted for each of the selected cities. Besides, environment effect by different travel purpose can be estimated from the above travel characteristics.

2.2. Variables

2.2.1. Measures of Land Use. In this study, two variables were selected for measuring the urban form, including the developed-area density and the land use balance. Each variable is explained as follows.

2.2.2. Density. To explore the correlation between urban form and travel activity, the density of population or employment is a common measurement of the built environment in previous study [17]. The residential density in TAZ i is calculated as the residential population divided by the gross area as follows (Table 1):

$$\text{Density}_i = \frac{R_i}{A_i}, \tag{1}$$

where R_i is the population of the ith TAZ and A_i is the area of the ith TAZ.

2.2.3. Land Use Balance. The concept of jobs-housing balance is familiar to transportation professionals which is measured by the deviation from a larger region's average balance [18]. It is more difficult to define the concept of a balance of land uses. The index used here is based on a measure of entropy, originally defined for the energy state of a system which is commonly used to quantify the uniformity of gaseous mixtures. The measure of entropy usually incorporates only a single summation (2). Cervero [3] first used the entropy measure to quantify the land use balance in looking at suburban employment centers:

$$\text{Entropy}_i = -\sum_{\lambda} \frac{P_{i\lambda} \ln\left(P_{i\lambda}\right)}{\ln\left(\lambda\right)}, \tag{2}$$

where $P_{i\lambda}$ is the proportion of land use type λ within the ith TAZ.

The entropy measure is normalized with respect to the natural log of the number of distinct uses considered and thus varies between 0 and 1, where 1 signifies perfect balance of the uses considered. The four ($\lambda = 4$) land use types which are considered distinct and used in the computation of the work entropy (job-housing balance) index are introduced as follows: residential, offices and research sites, industrial,

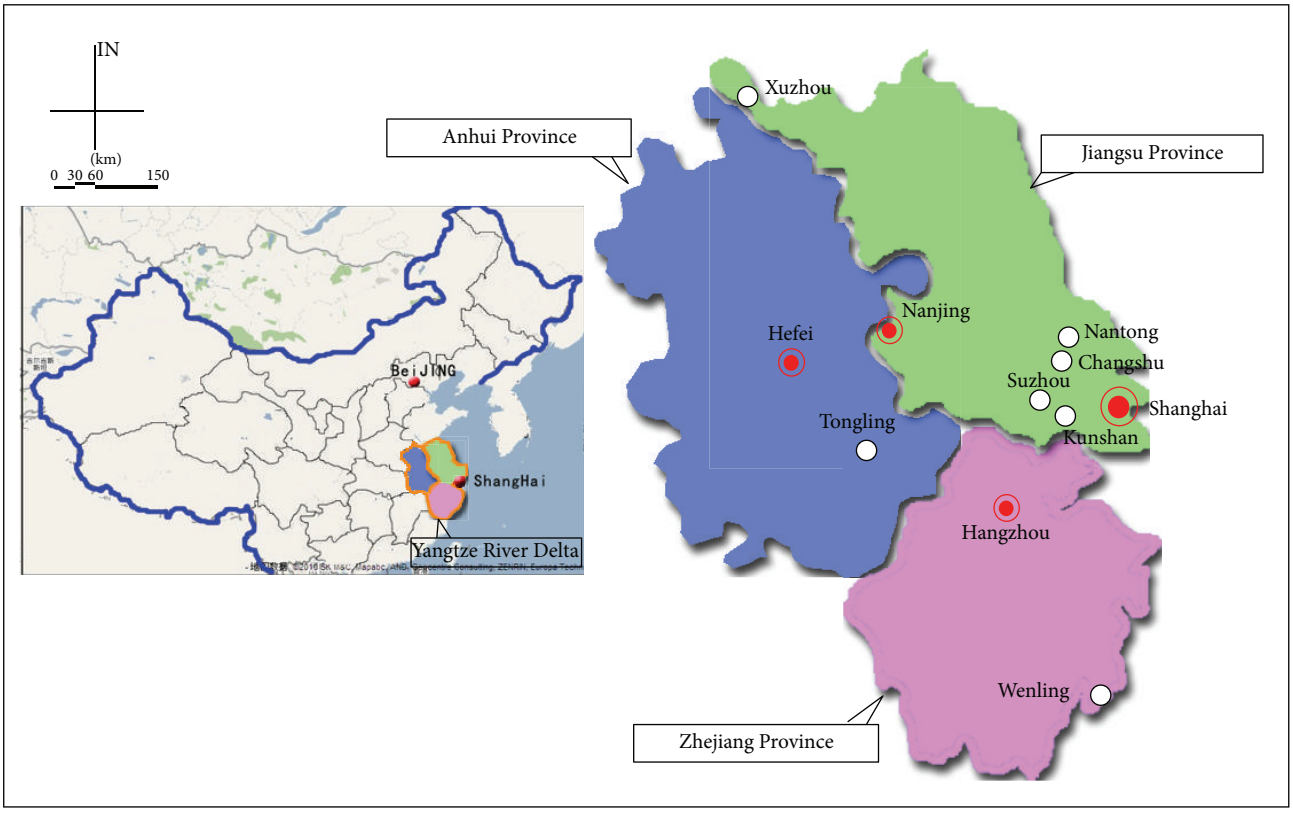

Figure 1: Location of the selected seven cities in China.

and ware housing. Besides this, a nonwork entropy (retail-housing mixing) measure is also computed; the four land use types include residential, commercial, public service, and park recreation ($\lambda = 4$). The means of entropy values in the 7 cities are described in Table 1.

2.2.4. Road Space per Person. Another important index is the development of the road network measured by the road space per person as shown in Table 1. It is calculated by (3) and the results are given in Table 1:

$$\text{road space}_i = \frac{d_i}{R_i}, \tag{3}$$

where d_i is the road space area of the ith TAZ.

Table 1 shows the descriptive statistics of urban form in the selected 7 cities. The mean of the city density ranges from 87 to 135 persons/ha. Among them, Xuzhou has the highest density (135 persons/ha); the density in other cities such as Kunshan, Suzhou, and Changshu is above the average density (107 persons/ha). But the density in Tongling is the lowest among all cities, which is 87 persons/ha. Other cities such as Wenling and Nantong have low densities.

Besides, the mean of the city work entropy involved ranged from 0.4 to 0.65. Xuzhou, Kunshan, Suzhou, and Tongling have higher entropy values; it means that in those cities industry locates near the residential areas. Comparatively, in those cities such as Changshu, Nantong, and Wenling, the employment separates farther from the house than others. Work entropy in Wenling is quite low which is 0.4. The mean of the nonwork entropy is estimated to be 0.57 to 0.7. The cities of high nonwork entropy are Xuzhou, Changshu, Kunshan, and Suzhou. This suggests that the subcenter commerce or community retail located near the house. The nonwork entropy is found to be much lower in Nantong, Tongling, and Wenling. In those cities the urban structure can be characterized by a lopsided concentration in a single central business district.

The mean of the road space per person is around 10.79 to 15.86 m^2/person. Among all cities, Kunshan, Suzhou, and Wenling have good economic conditions and more road investments, and thus the road space per person is higher than others. On the contrary, Changshu, Nantong, and Tongling have less road facility investments, and thus the road space per person is quite low.

2.3. Measures of Travel Behaviour. Several variables were selected to show the travel behaviour features, such as the modal split, travel time, trip purpose, and average speeds by modes. Then the trip length by purpose can be estimated from the above variables. Those variables are introduced in the following sections.

2.3.1. Modal Split. Data used for analysis were extracted from the surveys in the comprehensive transportation planning during the period of 2000–2004. The individual trips by walk, bicycle, bus, car, and motorcycle for work and nonwork

Table 1: Descriptive statistics of urban land use pattern in the 7 medium-sized cities.

City name	Population (thousand)	Urbanized area (km^2)	TAZ (Number)	Mean of density (person/ha)	Residence-industry mix entropy		Residence-commerce mix entropy		Road space per person
					Mean	SD	Mean	SD	m^2/person
Xuzhou	950	70.37	81	**135**	**0.65**	0.43	**0.7**	0.29	**12.91**
Changshu	550	50.93	43	**108**	**0.43**	0.38	**0.69**	0.24	**11.3**
Nantong	647	70.33	51	**92**	**0.48**	0.37	**0.63**	0.17	**10.79**
Kunshan	510	43.59	20	**117**	**0.56**	0.37	**0.74**	0.38	**15.86**
Suzhou	1250	107.76	116	**116**	**0.64**	0.38	**0.73**	0.24	**14.1**
Tongling	590	67.82	27	**87**	**0.59**	0.42	**0.67**	0.35	**11.21**
Wenling	970	100.00	86	**97**	**0.4**	0.42	**0.571**	0.38	**15.31**
Avg	781	72.97	61	107	0.54	0.40	0.68	0.29	13.07

Table 2: Modal splits based on work and nonwork trips in the 7 cities.

	Work trips (%)					Nonwork trips (%)				
	Walk	Bicycle	Bus	Car	Motor	Walk	Bicycle	Bus	Car	Motor
Xuzhou	15	62	16	3	4	36	39	16	6	3
Changshu	32	34	14	8	13	52	18	18	9	4
Nantong	6	55	9	6	24	22	37	14	11	15
Kunshan	19	54	6	8	13	66	20	3	6	4
Suzhou	17	64	7	4	8	49	33	11	3	3
Tongling	55	15	20	6	4	63	9	12	9	7
Wenling	7	41	9	12	31	27	34	15	13	11
Avg	**22**	**46**	**11**	**7**	**14**	**45**	**27**	**13**	**8**	**7**

purposes were investigated. The modal splits of work and nonwork trips for the seven selected cities are shown in Table 2.

We first analyzed the average of modal split based on the trip purpose. About half (45%) of the nonwork trips were completed by walking, and a much smaller share (22%) of the commuting trips was completed solely by walking. The share of bicycle was much higher for the work trips (46%) than for the nonwork ones (27%). Bus was a popular mode for both work trips and nonwork trips while the motorized vehicles (car and motorcycle) were more common among work trips (21%).

Then, we compared the difference of the modal split among these cities. These cities have a low level of public transportation use and rely to a correspondingly greater extent on nonmotorized vehicle (pedestrian and bicycle). For the work trips, the proportion of NMVS in Suzhou (81%), Xuzhou (77%), Kunshan (73%), and Tongling (70%) is much higher than the average value (68%) and is opposite to Changshu (66%), Nantong (61%), and Wenling (48%). The identical discipline happened to the nonwork trips.

The level of motorized vehicles (private car and motorcycle) used as a problem in terms of global warming is generally higher for the two cities in Wenling and Nantong. In the two cities, both work-commuting and nonwork trips are extremely high, with a significant dependence on the motorcycle and private car. Conversely, the share of motorized vehicles is much smaller in Suzhou and Xuzhou for both trip purposes.

2.3.2. Trip Length. The average trip length or trip distance by mode and purpose can also be estimated by the method as introduced in (1). The method is similar to that in Banister and Gallent [19] and Inoue et al. [20]. The relationships between the land use and the trip length for the work and nonwork purposes are analyzed and compared among these cities in China, based on the dataset introduced above:

$$\mathrm{Len}_{jk} = t_{jk} \times \overline{v}_j, \tag{4a}$$

$$\overline{\mathrm{Len}}_j = \frac{\sum_{k=1}^{n} \mathrm{Len}_{jk}}{n}, \tag{4b}$$

where t_{jk} is the travel time of mode j by different purpose of traveller k from person trip survey; $\overline{v}_j$ is the average speed of mode j from road speed survey; Len_{jk} is the trip length by purpose of traveller k mode j; $\overline{\mathrm{Len}}_j$ is the average trip length of mode j by purpose; and n is the number of travel survey samples.

Table 3: CO_2 unit emission rate by trip modes (g/km).

Walk	Bicycle	Bus	Car	Motorcycle
0	0	59	191	149

2.4. Measures of Traffic Emissions. It is true that there are many factors for sustainability in a city such as the energy consumption [21], noise [22], safety [23, 24], and economical efficiency. Among them, energy consumption is correlated closely with greenhouse gas (GHG) emissions. Previous research shows that about 33% of total greenhouse gas emissions in the United States are generated by the transportation sector, and CO_2 accounts for 95% of the greenhouse gas emitted from motorized transportation sources [21]. Thus, in this study, we choose CO_2 emission generated by vehicular traffic to assess environmental impacts for sustainable development.

The analysis of traffic CO_2 emissions requires details of trip characteristics for all purposes by mode and trip length. Obviously, the traffic emissions are related to mode of transportation and length of the trip. The methods for estimating the traffic emissions in terms of emission per trip (g/trip) are shown in Figure 2. The CO_2 unit emission rates for various modes of transportation are reported by Inoue et al. [20] and are given in Table 3. On basis of these emission rates, the emission per trip and emission per hectare can be calculated for comparison among the selected cities in China. The purpose is to assess the effects of modal split on emissions. Then the sensitivity analysis of modal shift is also analyzed for reducing emissions.

2.5. Procedures for Analysis. The procedures adopted for the data analysis in this paper are divided into four levels, as shown in Figure 3.

Step 1. The first level aims to investigate whether land use pattern influences modal split and evaluate its impact and find out the significant factors. Multiple regressions model was performed, with modal split based on trip purpose

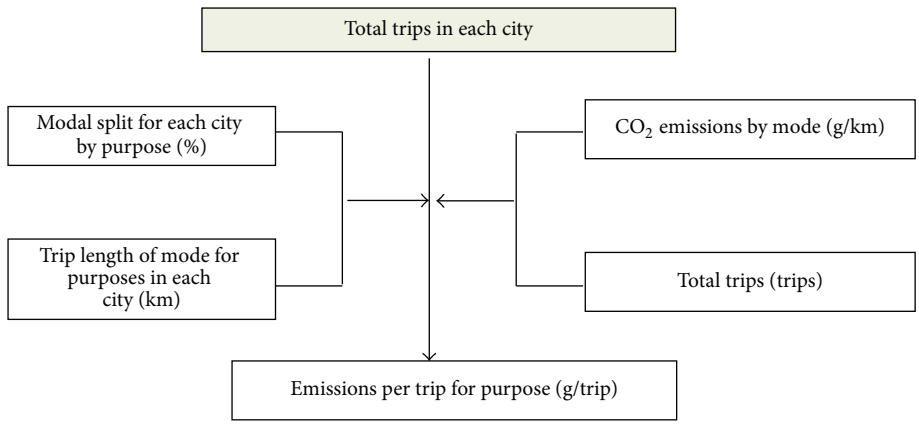

Figure 2: Method for estimating emission per trip.

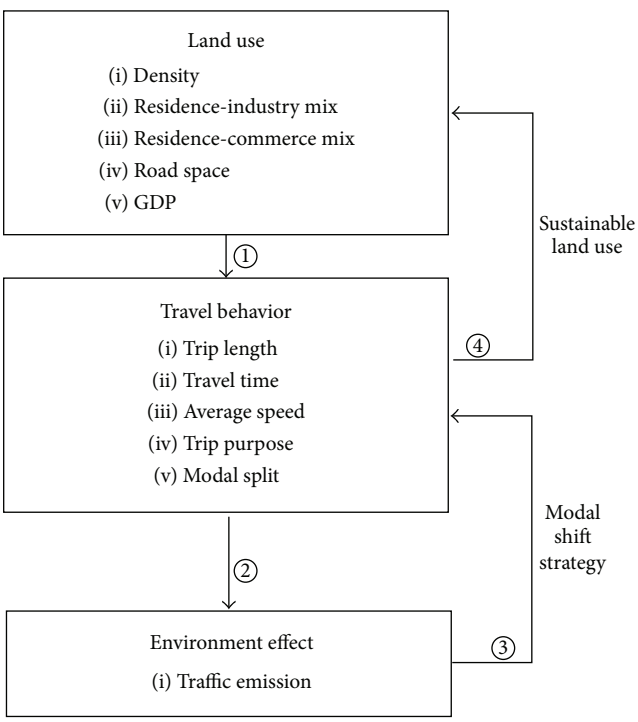

Figure 3: Procedure adopted for the data analysis in this paper.

serving as the dependent variables and the factors of land uses index as the explanatory variables:

$$P_j = \sum_{\mu} a_{j\mu} x_{j\mu} + \varphi_j, \tag{5}$$

where P_j is the travel proportion of modes j, $x_{j\mu}$ is the uth factors of land uses for measuring its effect on the travel mode j, and $a_{j\mu}$ are variable coefficients. A positive coefficient indicates that the proportion of mode is positively related to the land use factor and vice versa. φ_j is the constant value.

Step 2. The second level aims to develop a method to calculate the trip length and the emission per trip based on mode choice. The CO_2 unit emissions per trip for the various modes are determined as follows:

$$E = \sum_{j=1}^{5} P_j \times \overline{\mathrm{Len}}_j \times u_j, \tag{6}$$

where u_j is CO_2 unit emission rate by trip modes j, $\overline{\mathrm{Len}}_j$ is the trip length of modal j for each city, and E is the emissions per trip by purpose.

Step 3. After comparing the emission influenced by modal split among the cities of China, the logarithmic regression model can be developed to relate the emission per trip to the proportion of mode. Sensitivity analysis method on modal shift is carried out for reducing emissions. We can perform sensitivity analysis to calculate the change of share of each trip mode in order to reduce emission per trip to half. Then modal shift strategy can be proposed accordingly:

$$\begin{aligned} P_j &= \beta_j \ln(E) + \varepsilon_j, \\ \Delta P_j &= P_{j2} - P_{j1} = \beta_j \ln(E_2) - \beta_j \ln(E_1) \\ &= \beta_j \ln\left(\frac{E_2}{E_1}\right), \end{aligned} \tag{7}$$

where β_j is the regression coefficient of variable which evaluates the correlation between emission (E) and the proportion of trip mode P_j, ε_j is constant, ΔP_j is modal shift percentage of mode j, P_{j1} and P_{j2} are the percentage of mode j before and after modal shift, and E_1 and E_2 are the emission of mode j before and after the modal shift.

Step 4. Based on the regression analysis between modal split and the key land use index in Step 1, we can propose a sustainable land use pattern by modal shift strategy for a range of medium-size cities in China to help reduce emission:

$$\begin{aligned} P_j &= \lambda_{j\mu^*} x_{j\mu^*} + \gamma_j, \\ \Delta x_{j\mu^*} &= x_{j\mu^*{}_2} - x_{j\mu^*{}_1} = \frac{(P_{j2} - P_{j1})}{\lambda_{j\mu^*}} = \frac{\Delta P_j}{\lambda_{j\mu^*}}, \end{aligned} \tag{8}$$

Table 4: The model of urban form affecting mode choice for work trips.

	NMVS		Bus		Car		Motorcycle	
	B	Beta	B	Beta	B	Beta	B	Beta
Constant	0.307		0.147		0.136		0.418	
GDP	$4.92E-006^{*}$	0.484	$-2.5E-006$	−0.568	$-3.7E-007$	−0.122	$-2.1E-006$	−0.207
Road space	-0.029^{*}	−0.566	−0.004	−0.175	0.009	0.611	0.023	0.46
Density	0.003	0.405	−0.001	−0.229	−0.001	−0.341	−0.001	−0.2
Job-house balance	0.691^{**}	0.657	0.268	0.59	-0.21^{*}	−0.676	−0.765	−0.737
R^2	0.975		0.721		0.932		0.807	
F-value	19.425		1.294		6.848		2.09	

*statistical significance ≤ 1%.
**statistical significance ≤ 0.05%.

where $x_{j\mu^*}$ is the critical factors of land uses for measuring its effect on the travel mode j, $\lambda_{j\mu^*}$ is the regression coefficient of variable which evaluates the correlation between land use factor $x_{j\mu^*}$ and modal split P_j, γ_j is the constant, $\Delta x_{j\mu^*}$ is the sustainable optimal difference of key land use factor, and $x_{j\mu^*_1}$ and $x_{j\mu^*_2}$ are the key land use factors before and after corresponding to modal shift ΔP_j of mode j.

3. Results

3.1. Land Use Influence on Modal Split. Table 4 presents a model for estimating the urban form effect on work trip and nonwork trip characteristics.

3.1.1. Modeling Results for Work Trip. For the work trip, it can be seen from the beta value in Table 4 that the work entropy (jobs-housing balance) is the most important factor among all contributing factors in commuting travel activities. The factor was positively correlated with the trip of public transit and nonmotorized trip modes (NMVS, which includes the bicycle and walking trips) but was negatively correlated with car trip. The results are reasonable considering that because the short-distance work opportunity reduces commuting trip distance, the reduced distance made the personable motorized trips less important. According to our findings, as the land use balance (work entropy) increases by 10%, the percentage of car and motorcycle decreases by 2.1% and 7.65%, respectively. On the contrary, the NMVS and bus percentage increase by 6.91% and 2.68%.

Based on the modeling results, the road space also had important impacts on the commuting trip of NMVS, car, and motorcycle, but had small impacts on the bus trip. As the road space per person increases by 10 m^2/person, the percentage of NMVS will rapidly decrease by 29% while the car and motorcycle will increase by 9% and 23%. The future results prove the fact that road space will increase people's "driving pleasure" and promote more motorized commuting trips.

GDP was also an important factor, but its impacts were quite special. Among all the seven cities, the relationship between GPD and bus, car, and motorcycle was negative, but between GDP and NMVS it was positive. The results show that the use of motorized trip modes in commuting travels is not quite consistent with the increase of GDP. More specifically, in some areas with high GDP, people may not use motorized trip modes for commuting travels even if the average ownership of car is higher.

Our results show that increased density will increase the commuting trips of NMVS and decrease the trips of personal motorized modes. Although the conclusions are consistent with some other studies [25, 26], our results further show that the density index shows poor effect in comparison with land use balance for work trip. So the density is probably not a critical index for measuring the urban form effect on commuting travel characteristics.

3.1.2. Modeling Results for Nonwork Trip. The regression model of the nonwork trip is actually very similar to the work trip. The nonwork entropy (retail-housing mixing) is the most important contributing factor. As the nonwork entropy (retail-housing mixing) increases by 10%, the leisure trip percentage of NMVS will increase by 6.91%. It is noticed that the correlation between bus and nonwork entropy is negative, probably because for leisure trips public transit was less attractive than the NMVS.

For leisure trips, the impacts of road space on trip modes are different from those for work trips. The road space per person has a positive correlation with the leisure trip percentage of NMVS but has a negative correlation with that of motorized vehicle. The reason would be the fact that more road space promotes walk trips which is popular in leisure trips.

For leisure trips the impacts of GDP are also different from work trips. Modeling results indicate that as GDP increases, more people will choose car for leisure trips rather than NMVS. As the GDP per person increases by 10000 RMB, the car use will increase by 4.25%, but the nonmotorized trip mode will decrease by 5.1%.

For nonwork trips, increasing density will increase the use of public transit but decrease the trips of motorcycle. People will choose public transit for travel activities in the area with high density, which is consistent with Newman and Kenworthy [27]. However, the density is not a critical index as compared to the nonwork entropy for measure the urban form effect on leisure travel characteristics.

Table 5: The model of urban form affecting mode choice for nonwork trips.

	NMVS		Bus		Car		Motorcycle	
	B	Beta	B	Beta	B	Beta	B	Beta
Constant	−0.964		0.464		0.860		0.574	
GDP	$-5.1E-006^{**}$	−0.524	$3.61E-007$	0.112	$4.25E-006$	0.986	$-2.3E-007$	−0.052
Road space	0.042^{**}	0.864	−0.002	−0.126	−0.02	−0.947	−0.016	−0.697
Density	-0.003^{**}	−0.493	0.001	0.128	0.001	0.426	0.002	0.623
Retail-housing mixing	2.310^{**}	1.368	−0.498	−0.883	−1.084	−1.441	−0.629	−0.800
R^2	0.999		0.882		0.819		0.777	
F-value	474.547		3.734		2.263		1.746	

**statistical significance ≤ 0.05%.

3.2. Environmental Impact Associated with Mode Split. Table 5 shows the trip time information (minutes), average speed, and trip purpose for the nine cities. From these data, trip distance (km) and emission per trip are calculated. The relationships between the modal split and the environmental impact are analyzed and compared as follows.

Among the seven cities, Xuzhou is the most self-contained city which has the highest work entropy (about 0.65). Thus in the city the numbers of car and motorcycle trips for work trip are the lowest among these 7 selected medium-size cities. But the public transportation and bicycle modes are well received. The proportion of bus trips is more than 15% and the proportion of bicycle trips is high (62%). As a consequence, the emission per trip for work purpose in Xuzhou is only 286.5 g/trip which is about 45% less than the average value (525 g/trip). On the other hand, for the nonwork trip, the emission is 87.3 g/trip more as compared with that in the work trips. This is because the use of motorized vehicle (which is 6%) is 2% more than its use for work trip.

Suzhou is the largest medium-size city in the region of the YRD. In the past twenty years the city economy has changed from traditional manufacture into high-tech industry. The industry district was built jointly by Suzhou and Singapore. The city shows a trend of multidistrict, multicenter, and district self-contained area. As a result, within each district, the percentage of bicycle and public transit is very high for trips of all purposes. The average trip emission of work trip and nonwork trip is 337.7 g/trip and 317.6 g/trip, respectively, which is much less than the average (525 g/trip and 501 g/trip) value among the seven cities.

Kunshan is a new town with an area size of 43 km^2 and a population of 510,000. The scale of urbanized area is the smallest, and the commerce and the residence locate near each other. As a result, the mode shares of the nonmotorized trips are more than 80% in the nonwork trips. With the same discipline, because more nonmotorized cities have much less emission per trip, the emission per trip (262.1 g/trip) in Kunshan is the lowest among the 7 cities.

Tongling has the lowest density (about 87 persons/ha) among all selected cities. It has a total population of 590,000 with an area size of 67 km^2. There are a lot of industries in the city, and the traditional "compound" pattern makes workers live in the factory. Thus, walking and bicycling modes are popular in Tongling in work trips. It is shown in Table 6 that walking and bicycling are the most popular modes of transportation with a share of 70% for work travel in Tongling and the overall average trip length is only 4.3 km for commuting trips. The emission per trip (340.1 g/trip) in work trip is 35.2% less than the average value (525 g/trip).

Changshu is a historical and tourism city with a population of 55,000 and an area size of 50 km^2. In order to protect the old urban area in the inner city, the new development area has to be built outside the boundary of the inner city. It leads to the increase of journey length for travel from outlying areas to the inner city center. As a consequence, for both trip purposes, the mode shares of bus trips are up to 14% and the proportion of car trips is more than 8%. Also the trip length and emission are quite high. For work trip, the length (6.7 km) is 0.5 km greater than the average (6.20 km); the emission is higher than the average, and so does the emission for nonwork trip.

Nantong has a population of 647,000 and an area of 70 km^2. Because the traditional industries and residential areas are located near the coast in the city, they are separated far away from the center of the city. Therefore, the trip length for work and nonwork purposes is comparatively longer. Therefore, the share by nonmotorized modes is comparatively lower than other cities and the proportion of motorized vehicular trips is the highest for both purposes. As a result, the overall emission per trip for work and nonwork trips is rather high, especially for nonwork trip; the emission is 806 g/trip which is the largest among the 7 selected medium-size cities in YRD region of China.

Wenling has a population of 970,000 and its area size is about 100 km^2. Its economy is the best among all selected cities. The GDP per capita is 5,655 US$/person in 2002, which is 1.89 times the overall average GDP (2,986 US$/person) value in the 7 cities. With the existence of sufficient road network, the car and motorcycle ownerships are expected to be very high. For work trip, the mode shares of car and motorcycle trips are 12% and 31%, respectively. The overall average trip length (7.6 km) and emission (857.1 g/trip) are the highest among all selected cities for work purpose.

3.3. Sensitivity Analysis of Modal Split Shift for Reducing Emission. Figure 4 and Table 7 show the relationship between emission and the logarithm of modal split. From Figure 4

Table 6: Emission on trips of different purposes.

City	Modal	Work trips						Nonwork trips					
		Modal split	Trip time (min)		Velocity (km/h)	Total length (km)	Emission (g/trip)	Modal	Modal split	Trip time (min)		Velocity (km/h)	Total length (km)	Emission (g/trip)
			Avg	Std						Avg	Std			
Xuzhou	Walk	15	16.1	11.6	3.8	**5.8**	**286.5**	Walk	36	20.7	14.7	3.8	**5.74**	**373.8**
	Bicycle	62	23.2	12.9	11.5			Bicycle	39	26.4	18.2	11.5		
	Bus	16	36.4	17.1	19.4			Bus	15	36.5	19.4	19.4		
	Car	3	23.9	14.7	42			Car	6	25.1	17.5	42		
	Motor	4	23.5	13.7	31			Motor	4	23.6	19.4	31		
Changshu	Walk	32	18.6	10.3	3.3	**6.7**	**650.2**	Walk	52	27.3	16.2	3.3	**6.09**	**555.6**
	Bicycle	34	26.3	14.4	12.1			Bicycle	18	27.1	15	12.1		
	Bus	14	35	15.3	15.5			Bus	18	38.2	16.8	15.5		
	Car	8	36	20	39.5			Car	9	33.8	18.9	39.5		
	Motor	13	21.8	10.7	29.9			Motor	4	31.5	15.9	29.9		
Nantong	Walk	6	19.4	13.6	2.8	**7.3**	**679.7**	Walk	22	23.9	13.1	2.8	**7.77**	**806.3**
	Bicycle	55	25	14	10.4			Bicycle	37	26	14	10.4		
	Bus	9	43	15.7	17.1			Bus	14	44.7	17.3	17.1		
	Car	6	35.7	19.8	33.9			Car	11	35.9	17.6	33.9		
	Motor	24	24.9	13.9	25.6			Motor	15	27.9	17.3	25.6		
Kunshan	Walk	19	16.3	10.4	2.9	**5.9**	**529.8**	Walk	66	16.3	10.4	2.6	**2.52**	**262.1**
	Bicycle	54	19.1	11.7	10.7			Bicycle	20	19.1	11.7	9.7		
	Bus	6	31.9	11.4	17.5			Bus	3	31.9	11.4	15.9		
	Car	8	18.8	7.1	34.8			Car	6	18.8	7.1	31.7		
	Motor	13	22.7	18.8	26.3			Motor	4	22.7	18.8	24		
Suzhou	Walk	17	15.5	10.2	2.9	**5.8**	**337.7**	Walk	49	22.5	10.7	2.9	**4.9**	**317.6**
	Bicycle	64	24.7	13.3	10.7			Bicycle	33	25.4	12.7	10.7		
	Bus	7	48.4	13.3	17.5			Bus	11	49.4	15.3	17.5		
	Car	4	38.1	16.6	34.8			Car	3	46.5	18.1	34.8		
	Motor	8	21.9	10.5	26.3			Motor	3	28.3	16.3	26.3		
Tongling	Walk	55	20.8	14.4	3	**4.3**	**340.1**	Walk	63	23.6	12.2	3	**5.4**	**568**
	Bicycle	15	23.8	14.5	10.7			Bicycle	9	23.8	13.4	10.7		
	Bus	20	34.4	15.9	18.3			Bus	12	39.9	16.3	18.3		
	Car	6	25.8	12.1	34.4			Car	9	37.5	19.4	36.4		
	Motor	4	16.6	6.2	27.5			Motor	7	23.9	16.1	27.5		
Wenling	Walk	7	15.4	8.9	3.2	**7.6**	**857.1**	Walk	27	21.7	15.5	3.2	**6.27**	**628**
	Bicycle	41	23.1	9.3	11.7			Bicycle	34	21.3	13.2	11.7		
	Bus	9	29.6	11.6	19.2			Bus	15	31.6	14.3	19.2		
	Car	12	26.3	9.4	38.1			Car	13	25.1	11.8	38.1		
	Motor	31	18.9	10.3	28.8			Motor	11	18.2	13.3	28.8		

Table 7: Logarithm related model of modal split with emission for all works.

	Work trip				Nonwork trip			
Parameters	NMVS	Bus	Car	Motor	NMVS	Bus	Car	Motor
Constant	2.104	0.421	−0.315	−1.214	2.184	−0.356	−0.349	−0.473
$b1$	−0.230**	−0.049	0.062**	0.218**	−0.237**	0.071**	0.069**	0.088*
R^2	0.754	0.194	0.73	0.839	0.921	0.724	0.666	0.463
F-value	15.321	1.207	13.5291	26.037	58.191	13.091	9.956	4.306

*statistical significance ≤ 1%.
**statistical significance ≤ 0.05%.

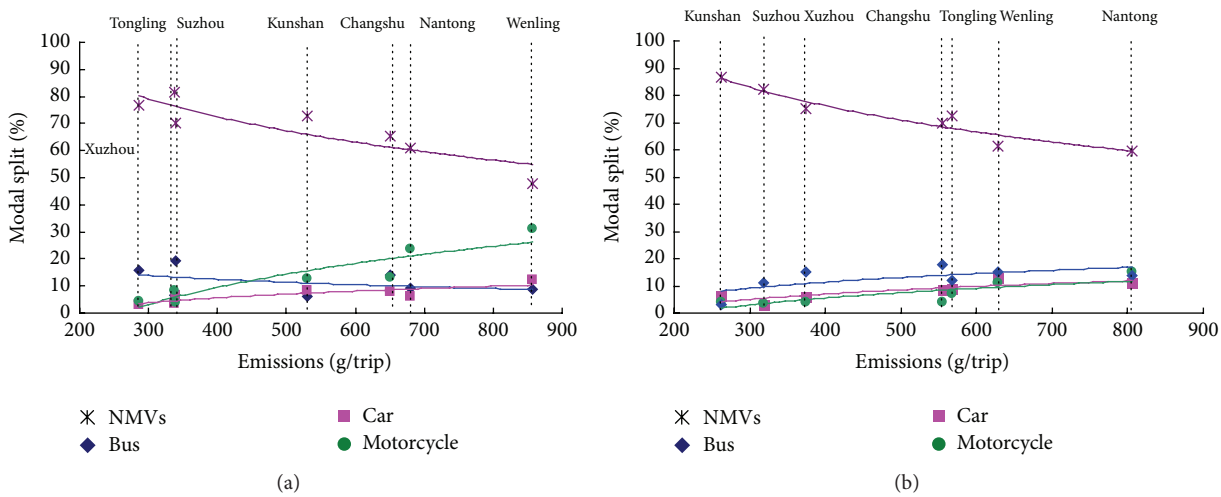

Figure 4: (a) Correlation of modal split with emission for work trips. (b) Correlation of modal split with emission for work trips for nonwork trips.

and Table 7, it was found that the increase of emission is accompanied with the usage of motorized vehicles. On the contrary, less emission has been linked to the growing use of the walk and bicycle (it was found that the emission increases significantly with car and motorcycle trips but decreases effectively with increasing of the walking, bicycle, and bus trips).

For work trips, to reduce the emission by half, the mode share of NMVS needs to increase by $0.23 * \ln(0.5) = 15.96\%$. Conversely, it is accompanied with the mode share of car and motorcycle trips decrease by $0.062 * \ln(0.5) = 15.14\%$ and $0.218 * \ln(0.5) = 4.30\%$. The bus more especially provides a weak negative link to the emissions: the mode share of bus trips needs to increase by $0.049 * \ln(0.5) = 3.42\%$.

For nonwork trips, to reduce the emission by half, the mode share of NMVS needs to increase by $0.237 * \ln(0.5)\% = 16.46\%$. Conversely, it is accompanied with the mode share of car and motorcycle trips decrease by $0.069 * \ln(0.5)\% = 4.79\%$ and $0.088 * \ln(0.5)\% = 6.11\%$. The mode share of bus trips more especially also needs to decrease by $0.071 * \ln(0.5)\% = 4.93\%$.

For sustainable development, how can we reduce the traffic emissions effectively? The modal shift from the motorized to nonmotorized modes and the shift from the car or motorcycle to bus would have great benefit for environmental improvement. The sensitivity of modal shift for reducing traffic emissions is analyzed as Table 8 shows.

Table 8: The sensitivity of modal split shift for reducing traffic emission.

	Emission per trip decrease by half	
Modal shift (%)	Work trips	Nonwork trips
NMVS	15.96	16.46
Bus	3.42	−4.93
Car	−15.14	−4.79
Motorcycle	−4.30	−6.11

Table 8 shows that a modal shift reduces emission by half in those medium-sized cities in China. For work trips, about 15.14% modal shift from car to bus or NMVS leads to the reduction in emission per trip by half. Similarly, about 4.3% modal shift from motorcycle to the bus or NMVS leads to a reduction of emission per trip by half. Moreover, for nonwork trips, the substantial reduction in emission per trip by half can be obtained by a 4.93% modal shift from bus to NMVS, a 4.79% modal shift from car to NMVS, and a 6.11% modal shift from motorcycle to NMVS.

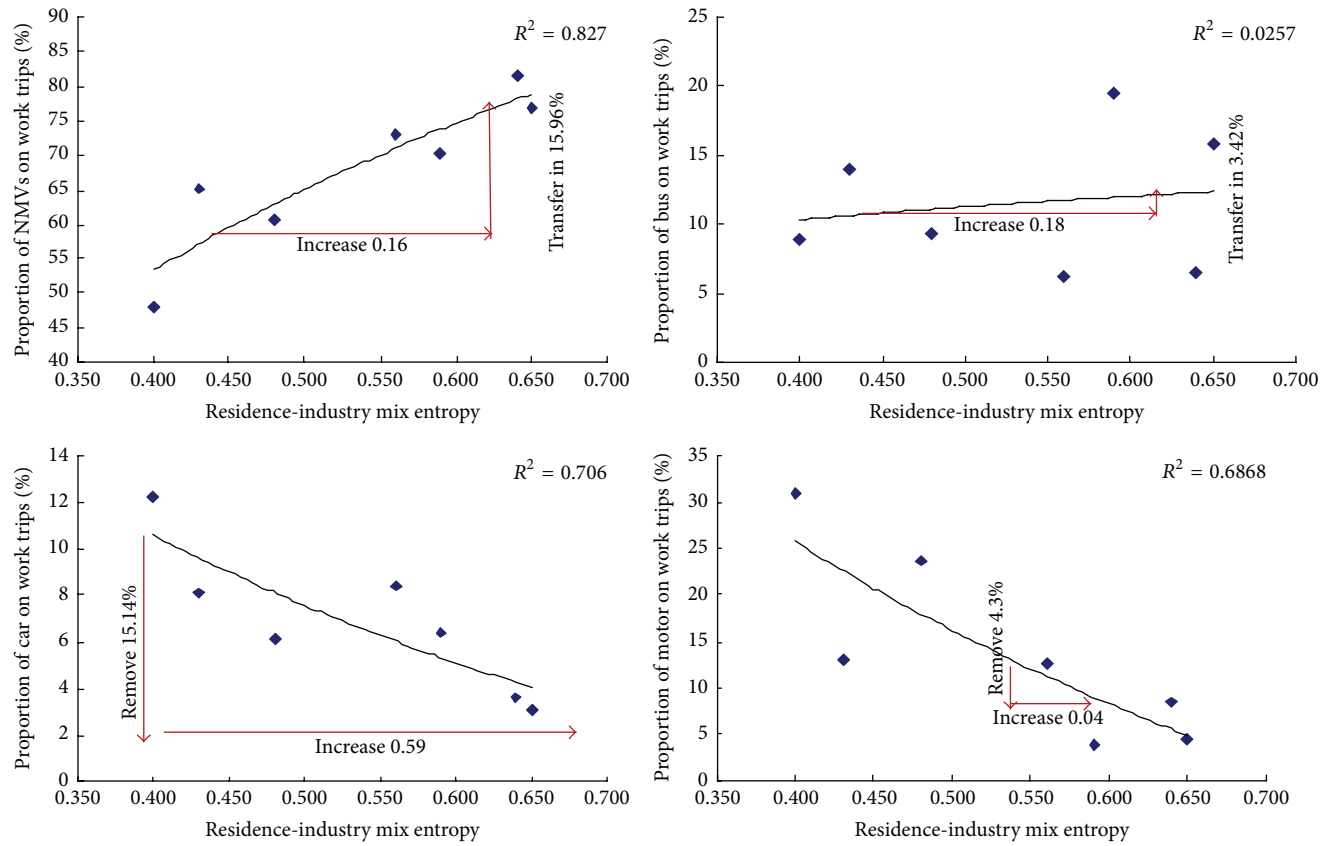

Figure 5: The sustainable residence-industry entropy by mode split shift for work trips.

3.4. Sustainable Land Use Pattern by Modal Shift Strategy. Since the work and the nonwork entropy are the most important parameters influencing travel behaviour in the 7 cities, a binary regression is applied (Figures 5 and 6). Moreover, a stepwise analysis is used to study the sustainable land use pattern by modal shift strategy for Chinese medium-size cities so as to reduce traffic emission.

For work trips, in order to reduce the emission per trip by half, the modal split of bicycle needs to be transferred by 15.96% and the residence-industry mix entropy needs to be increased by 0.16. Similarly, to achieve the same reduction in emission, the modal split of bus needs to be transferred by 3.42% and the entropy index needs to be increased by 0.18%. For car and motorcycles, to reduce the emission by half, the modal split shoud be removed by 15.54% and 4.43%, respectively, and the entropy index should be increased by 0.59 and 0.04.

For nonwork trips, our models for nonwork trip are similar to those for work trip. If the traffic emission per trip decreases by half, the modal split of NMVS should be transferred by 15.96%, which lead to the fact that the residence-commerce mix entropy increases by 0.1. To achieve the same decrease in emission, the mode share of bus, car, and motorcycle should be removed by 4.93%, 4.79%, and 6.1%, with the corresponding entropy index increasing by 0.12, 0.07, and 0.14, respectively.

4. Conclusions

With the recent rapid growth of urban development in medium-size cities in China, traffic emission becomes more and more severe in recent years. This study proposed a rational land use pattern for those cities to help reduce traffic emissions in urban areas. In this study, it was found that land use mix was one of the most influential parameters for both purposes. A region with a job-housing balance caused a rise in the mode share of NMVS and bus and decrease in car (motor) trips for work trip. Equally, the effect of increasing retail-housing mixing on leisure travel behaviours (except for bus share) was similar to job-housing balance. But the density was probably not a critical index for measuring the urban form effect on travel characteristics.

The results in the study confirmed the existence of a close relationship between the modal and traffic emission. It was found that that the increase of trip length was associated with the increase in the usage of the motorized vehicles. On the contrary, if more travel is made by nonmotorized modes, the average trip length will be shortened and the traffic emissions will be reduced remarkably. The methods proposed in this paper can be used to calculate the aggregated emission per trip (g/trip). It was also demonstrated that the city with a large number of motorized vehicle trips and long-distance travel has the largest emission per trip.

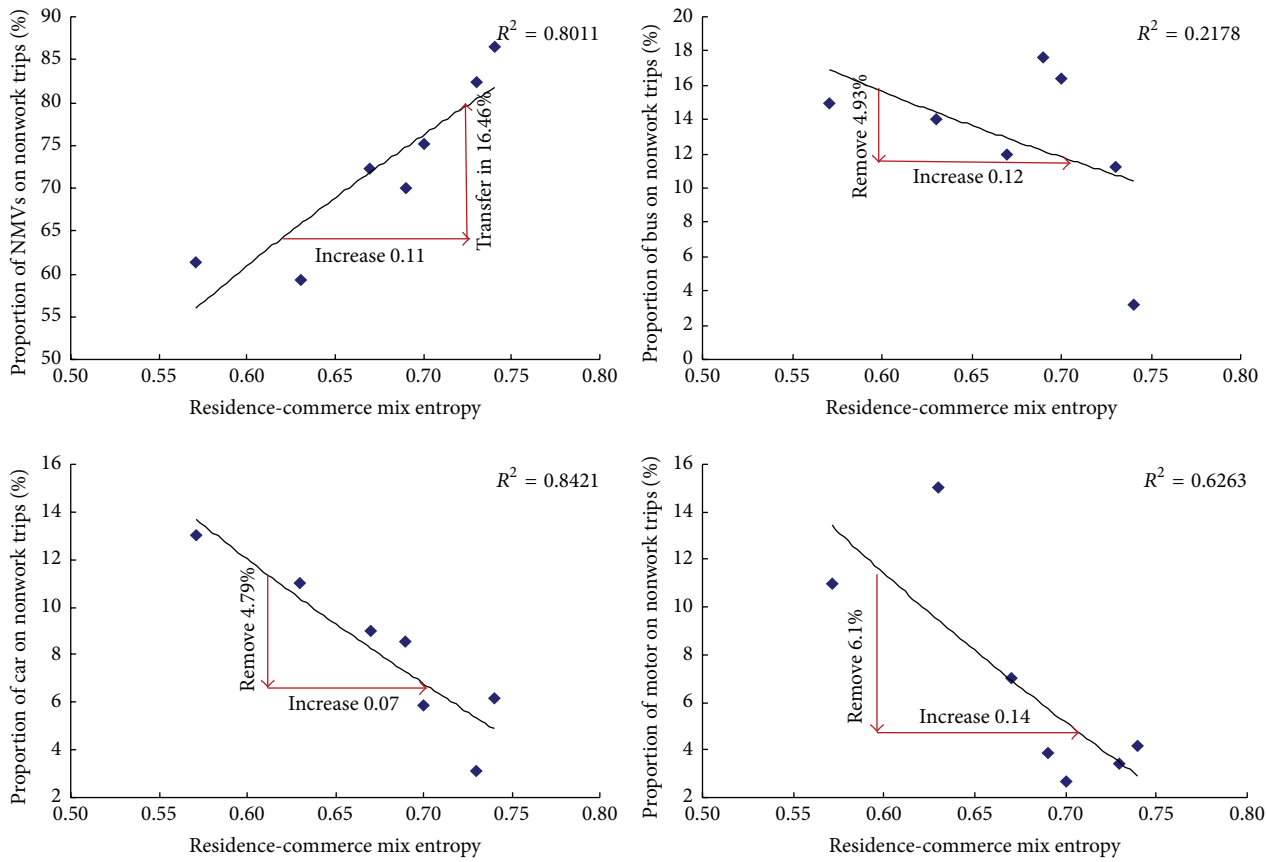

Figure 6: The sustainable residence-commerce entropy by mode split shift for nonwork trips.

The emission was found to be positively related to the car and motorcycle trips but was negatively linked with the proportion of bicycle, walk, and bus trips. As a result, the modal shift from the motorized vehicle to nonmotorized modes and the shift from car and motorcycle to bus could bring great benefit for the development of sustainable urban form. For work trips, about 15.14% of modal shift from car to NMVS or bus and 15.14% of modal shift from car to NMVS will lead to the reduction in emission per trip by half. About 4.3% of modal shift from motorcycle to NMVS or the bus will achieve the same effect. Moreover, for nonwork trips, the reduction in emission per trip by half can be obtained by a 4.93% of modal shift from bus to NMVS, a 4.79% of modal shift from car to NMVS, or a 6.11% modal shift from motorcycle to NMVS.

In the end of the study, constructive suggestions for sustainable land use pattern by modal shift strategy for medium-sized cities were provided. For work trip, if we would like to reduce traffic emission per trip by half, the modal split of NMVS and bus should be transferred by 15.96% and 3.42%, respectively, and the residence-industry mix entropy should be increased by 0.16 and 0.18 relevantly. Also, for the nonwork trip, the removal in the modal split of car and motorcycle will increase the residence-retail mix entropy. To achieve the same decrease in emission, the car and motorcycle should be removed by 4.79% and 6.1%, with the corresponding residence-commerce mix entropy index increasing by 0.07 and 0.14.

In conclusion, by analyzing the relationship among land use, modal split, and emission, this study provided a rationale land use pattern by modal shift strategy by for reducing traffic emissions in medium-sized cities in China. However, it is worth noticing that due to the difference in the urban form characteristics, land use balance may vary from one country to another. Their relationships with travel behaviours are different as well. In our study, the density is not a critical index as compared to the nonwork entropy for measuring the urban form effect on travel characteristics in Chinese medium-sized cities, but other researches conducted by Newman and Kenworthy [27] show that the density has a very strong impact on passenger transportation in the USA. As a result, no universal standards can be adopted for all cities. In our future studies, we will continuously conduct research on the contributing factors in those cities and explore the source of the difference between factors. However, the research logic and the modeling method proposed in this study can be used in other cities to achieve the sustainable development of cities and low carbon emission. Based on the methodologies in our study, the complex relationship between land use and travel behaviour could be evaluated and the optimal land use strategies can be proposed. The only difference could be that the impact of the contributing factors and their relationships

with land use as well as the detailed strategy could be different to some extent. As a consequence, in every case, one should first analyze the existing local relationships between land uses and transportation in order to ensure that any policies subsequently applied would be effective. It is also assumed that a general trend towards more mixed urban structures should be adopted in all cases to enhance sustainable travel patterns.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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