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A RESIDENTS-AUTONOMOUS-CHOICE-BASED TRAVEL CO2 EMISSIONS EFFECT EVALUATION METHOD FOR PUBLIC SERVICE FACILITIES LAYOUT AT COUTY LEVEL

Zhang Yehui[1], Yan Fengying [1*]

1 School of Architecture, Tianjin University

ABSTRACT

The allocation of public service resources in counties is more dependent on government investment than that in urban areas, which would reduce the availability of these services. Besides, the layout of public service facilities has a great impact on the spatial distribution of residents' travel demands, which may affect the CO_2 emissions generated by travel behaviors. Therefore, the environmental costs should be emphasized when considering the layout of public service facilities in county areas. In this study, we established a residents-autonomous-choice-based travel CO_2 emissions evaluation method by introducing scale characterization factor. With this method, we figured out the total amount, the spatial distribution and reduction potential of CO_2 emissions generated by residents' medical trips in Changxing County. The results show that the total monthly CO_2 emissions of residents' medical travel behaviors in Changxing are 243.56 tons. Besides, the central area of Changxing county and Sian town have formed obvious cold spots of per capita CO_2 emissions from medical travel, while Baixian and border of Xiaopu Town and Sian Town have formed obvious hot spots. By calculation, the potential capacity of CO_2 reduction by optimizing the layout of medical facilities is 154.81 tons, accounting for 63.56% of the current emissions.

Keywords: low carbon county, Layout of public service facilities, travel CO_2 emissions, residents' autonomous choice, spatial distribution, CO_2 reduction potential

NONMENCLATURE

Abbreviations	
IPCC	Intergovernmental Panel on Climate Change

Symbols	
i	Set of residential areas locations
j	Set of current public service facilities locations
P_{ij}	Probability of residents using public service
S_j	Scores of service ability of public service facilities
D_{ij}	Road network distance between residential area I and public service facility J
β	Distance friction coefficient
CE	Total residents' travel CO2 emissions
D_{kij}	Mileage from residential area I to facility point J using K-type travel mode
α_k	CO2 emission factor of K-type travel mode
W_i	Population of residential area I
F_i	Monthly travel frequency of Residents for access to public services
Z_k	Proportion of K-type traffic modes

1. INTRODUCTION

In the Paris Agreement, China committed to reduce CO_2 emissions per unit of GDP by 60%-65% in 2030 compared with 2005, making carbon emissions reduction a national demand and an obligation for the country. The experience of western urban development shows that the proportion of carbon emissions generated by residents' travel behaviors would face a gradual increase for the cities at the post-industrialized stage, given the growth of population and cars, and "de-industrialization" of industrial structure.[1] Thus, reducing travel CO_2 emissions has become an important issue in low-carbon development.

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Urban planning has a lock-in effect on the operation of urban factors [2]. Public service facilities, one of the core elements of urban and rural areas, could reshape the way of production and life and have a long-term and structural impact on residents' travel CO_2 emission through their spatial layout.

Current CO_2 emission effect evaluation of public service facilities layout is the basis of low-carbon optimization of the public service facilities distribution. However, extant studies have not yet formed a systematic method for the evaluation. The inventory method proposed by the IPCC only considers the fuel combustion carbon emissions of the transportation industry in the energy sector without taking the residents' daily travel CO_2 emissions into account[3]; Currently, the calculation of travel CO_2 emissions based on residents' travel survey has become the mainstream method in related studies, but most of them focus on the factors affecting travel CO_2 emissions in built environment. Yang (2014) analyzed the basic characteristics and influencing factors of household travel CO_2 emissions in Shanghai by questionnaires on household travel behavior[4]; Huang et al. (2015) analyzed the relationship between family socio-economic attributes and household travel CO_2 emissions[5]; Jiang (2016) calculated the CO_2 emissions of Beijing residents' household trips in work days by using the survey data of Beijing residents' activity logs[6]. Most of extant studies rely on quantitative mathematical calculation of geography disciplines, lacking of the analysis of travel CO_2 emission effects associated with spatial distribution. However, the combination of quantitative analysis and urban space is essential to the implementation of urban planning policies.

To fill this gap, this paper puts forward a systematic method of travel CO_2 emission evaluation under the layout of public service facilities including three steps: "Autonomous choice simulation of travel based on probabilistic OD matrix", "Characteristic extraction of residents' travel behavior in access to public services" and "Evaluation of travel CO_2 emission effects".

2. METHODOLOGY

2.1 Autonomous choice simulation of travel based on probabilistic OD matrix

The probability of residents' autonomous choice in choosing public service facilities is a kind of feedback from the interaction between the settlement and the facilities. It has been widely proven that the probability is related to the scale of the facilities and the distance between the residential areas and the facilities. Drezner T (2007) pointed out that the effect of the medical facilities is directly related to the scale and the service level of them[7]; Bruno(2015) believes that the probability of a resident selecting a facility is a function related to the attraction of the facility, the demand distribution and the Euclidean distance between the facilities[8].

Huff model is a classic model in the theory of spatial interaction which was first proposed by David Huff in 1963 and was used to predict the size of the business circle. The traditional Huff model uses a single variable to characterize the scale of public service facilities. We introduce the factor Sj which stands for the service capability score, which is calculated through factor analysis method taking into account the multivariate variables that affect the service level of public service facilities. On this basis, the ratio of the amount of resources that a single settlement can obtain at a facility to the total amount of resources available to the settlement is used as the probability of the resident selecting one facility among the same type of facilities. The formula is as follows:

$$P_{ij} = \frac{S_j / D_{ij}^{\beta}}{\sum_{j=1}^{n} (S_j / D_{ij}^{\beta})} \quad (1)$$

2.2 Characteristic extraction of residents' travel behavior in access to public services

Travel behavior is a direct factor affecting residents' CO_2 emissions, including the mode of travel that affects the choice of CO_2 emission factors, travel frequency which refers to the number of trips for a specific purpose during the study period, and acceptable time of travel which is one of the judgment conditions for residents to make a choice in the same type of public service facilities. When the travel time is greater than a certain threshold, it will be considered that residents give up choosing the public service facilities.

Because of the insufficient coverage of big data and the difficulty in obtaining micro-observation data for specific travel purposes in counties, the Stated Preference Data obtained by the travel questionnaire is better than the Revealed Preference Data obtained by the utility function based on hypothetical scenarios in reflecting real residents' choices. We also use travel questionnaire and carried out the auxiliary verification by calculating the average travel time for residents to get the medical facilities nearby at all levels based on the location allocation model of GIS.

2.3 Evaluation of travel CO_2 emission effects

The evaluation of CO_2 emissions effect of residents' access to public services facilities in this paper includes three aspects: the total travel CO_2 emissions, the spatial distribution analysis of travel CO_2 emissions per capita, and the potential assessment of travel CO_2 emissions reduction.

Scholars often use the CO_2 emission factors per mileage of each travel modes multiplied by driving mileage of various travel modes to account the travel CO_2 emissions in order to avoid the difference between regions. The model is as follows:

$$\mathrm{CE} = \sum_{i \in M}^{m} \sum_{j \in N}^{n} \mathrm{D_{kij}} \alpha_{\mathrm{k}} \mathrm{W_i F_i} \quad (2)$$

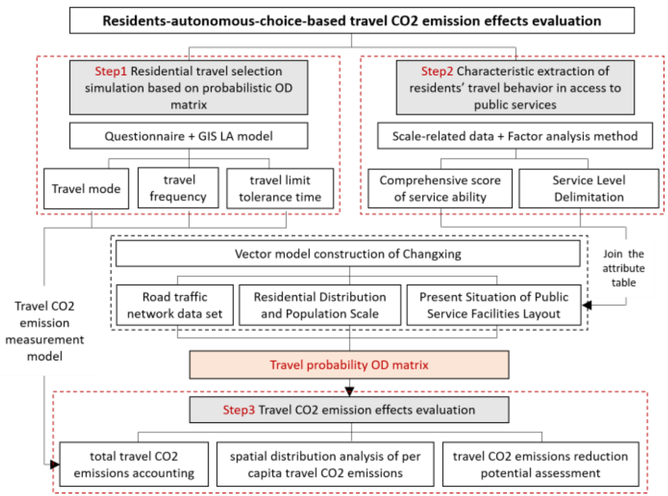

Fig 1. Overall framework

Most extant studies obtained travel OD between residence and destination of the respondents from POI. But this method is difficult to estimate data outside the sample because the selection of respondents is highly subjective. As residents' travel mode choice is highly sensitive to travel distance, we estimate the overall travel structure by summarizing the travel structure of sample data in different distance interval to reduce the impact of uneven distribution of sample data on the overall situation. Therefore, the above model is transformed into the following form:

$$CE = \sum_{i \in M}^{m} \sum_{j \in N}^{n} D_{ij} Z_k \alpha_k W_i F_i \quad (3)$$

In this study, spatial autocorrelation is used to analyze the spatial distribution features of travel CO_2 emissions. We use global spatial autocorrelation by Moran's I index to determine whether there is spatial agglomeration of travel CO_2 emissions, and local spatial autocorrelation by Getis-Ord General G index to identify high/low clusters of per capita carbon emissions and try to find out the possible causes.

We take the residents' acceptable time of travel as the constraint condition, and the CO_2 emissions beyond this time can be considered as the potential reduction of travel CO_2 emissions that can be reduced through the optimization of public service facilities' layout.

3. A CASE STUDY IN CHANGXING, CHINA

3.1 Data preparation and processing

We divided the road into eight levels (Tab.1) and established the road traffic network data set of based on GIS. We chose three typical sections of roads at all levels, and set the average speed of each level by calculating the average speed of each section in 9:00-10:00 and 14:00-15:00 in Monday, Wednesday and Saturday through Baidu Map.

Tab.1 Average speed of roads at all levels in Changxing

Road's level	Average speed (km/h)
highway	80
national road	45
provincial road	40
County/township road	45
County center main road	15
County center sub-main road	15
Town road	25
Village road	35

By the end of 2017, Changxing had four sub-district office communities, nine towns and two townships with a total population of 634486. There are 25 medical facilities in Changxing. We located distribution of residential area and the facilities by POI data and join these points with population, service capability score and other non-spatial attribute data.

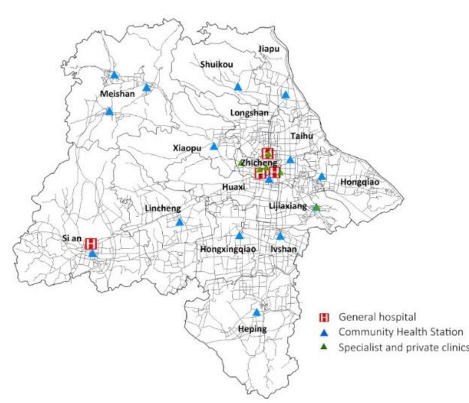

Fig 2. Distribution of Medical Facilities in Changxing

3.2 Classification of service level of current medical treatment facilities in Changxing

This paper constructs 11 indicators(Tab.2) from three aspects: the number of technicians, medical equipment and the ability of diagnosis and treatment, which are the main factors that residents consider when choosing a medical facility to obtain the service capability score of each medical facility and substitutes the scale representation factor Sj mentioned above. The service capacity level of the current medical facilities in Changxing is divided into three levels to define the acceptable time of travel, in addition, the service level of level 3 is the highest. After calculating, there are three level 3 medical facilities, eight level 2 medical facilities and 14 level 1 medical facilities.

Tab.2 Average speed of roads at all levels in Changxing

Factors	Variable	Indicator items
Health technical personnel	X_1	Number of practicing physician
	X_2	Number of practicing assistant physician
	X_3	Number of registered nurse
	X_4	Number of pharmaceutical personnel
	X_5	Number of inspectors
	X_6	Number of imaging staffs
	X_7	Number of other health technicians
Medical equipment	X_8	Number of beds
	X_9	Number of managers
Ability of diagnosis and treatment	X_{10}	Total number of patients
	X_{11}	Number of discharged patients

The KMO statistic is 0.794, greater than 0.7 that means the analysis results are acceptable and the significance of Barlett test was 0.000, less than 0.01 which means the variables were significantly correlated. From this, we can get the service capability score and level medical facilities in Changxing.

3.3 Characteristics of residents' medical travel behavior in Changxing

3.3.1 Travel structure

We divided the travel mode into 6 types: walking, bicycle, electric bicycle, motorcycle, bus and car. The results showed that the proportion of car travel is large in medical travel to all level facilities and increased with the increase of travel distance in a certain travel distance range. But when the travel distance exceeded a threshold, the proportion of car travel tend to stabilize or decreased sharply. In addition, the acceptable time of travel became shorter with the decline of medical facilities service level and the proportion of car trips decreased significantly. The proportion of electric bicycle travel also showed a similar trend while the trend of bus-travel proportion increased with distance became more obvious with the decline of service level. The proportion of motorcycle travel is very small.

3.3.2 Travel frequency

According to the survey of residents' travel, the frequency of residents' travel to level 3 medical facilities is 0.6 times per month, and 0.44 times per month to level 1 and level 2.

3.3.3 Acceptable time of medical travel

We compared residents' average travel time to all level medical facilities nearby with the results of the questionnaire survey, the acceptable time of medical travel is defined (Tab.3).

Tab.3 Acceptable time of medical travel

Grade	Average travel time to hospital nearby (min)	Acceptable time of travel obtained by questionnaire (min)	Acceptable time of travel (min)
3	23.75	25	25
2	13.43	12	12
1	11.91	12	12

3.4 CO_2 emission effect evaluation of medical treatment facilities' layout in Changxing

3.4.1 Calculation

According to the existing research, the distance friction coefficient fluctuates between 0.95 and 2.1, and 2 is more appropriate at the county level [9]. Therefore, we make β=2 in Formula (1), and based on the method mentioned above, the results of Changxing residents' medical travel CO_2 emissions are obtained.

Tab.4 Total CO_2 emissions of medical travel in Changxing

Sources \ Grade	3	2	1	Monthly total travel CO_2 emissions (Tons)
electric bicycle	7.35	5.67	1.49	14.52
motorcycle	1.12	0.53	0.01	1.66
bus	12.05	2.32	1.23	15.60
car	146.08	48.36	17.34	211.78
subtotal	166.59	56.89	20.08	243.56

According to the results, CO_2 emission from travel to level 3 medical facilities is 166.59 tons, accounting for 69% of the total emissions. It is the main source of CO_2 emission from medical travel in Changxing which means the planning of level 3 medical facilities is the key object of optimization of medical facilities layout considering environmental costs. Besides, car emission accounts for more than 50% of the total which is the main factor affecting the CO_2 emissions of medical facilities at all levels, followed by electric bicycles and buses.

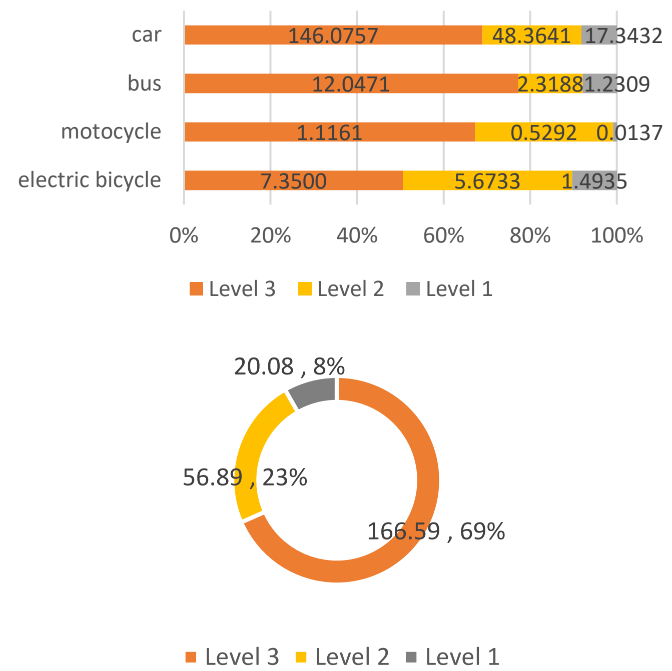

Fig 3. CO_2 emissions of medical travel at all levels

3.4.2 Spatial distribution analysis of per capita travel CO_2 emissions

The calculated Moran's I index is 0.843 (> 0), with a Z-score(the test threshold of 99% confidence interval) of 31.976(> 2.58) is 2.58. This suggests that the CO_2 emissions from medical travel in Changxing have obvious clustering characteristics on the global level.

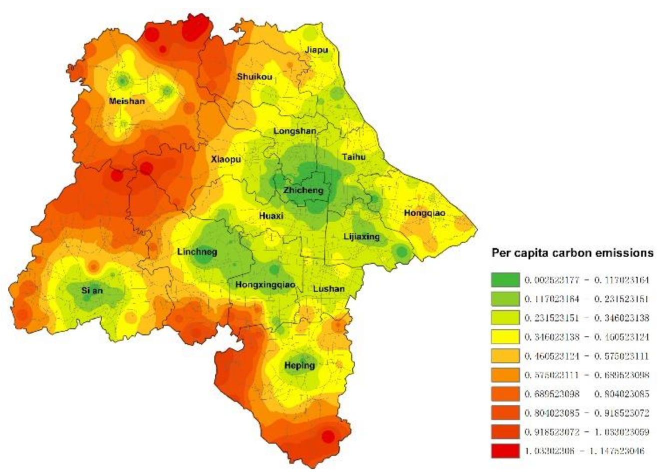

Fig 4. Spatial distribution of per capital CO_2 emissions from medical travel in Changxing

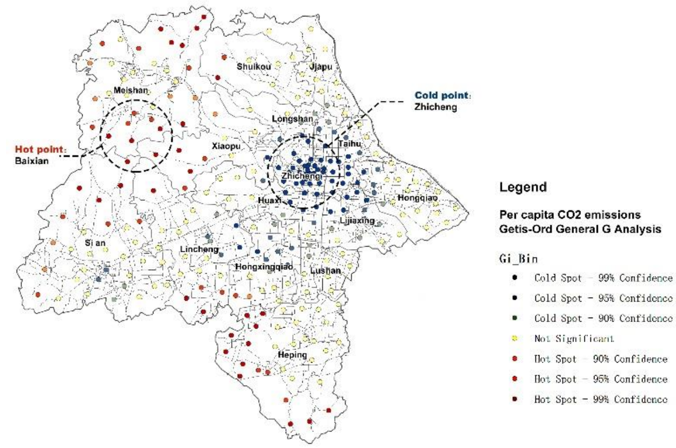

Fig 5. Hot spots and cold spots of per capital CO_2 emissions from medical travel in Changxing

The local special autocorrelation analysis displayed that the county center and Si'an have formed obvious cold spots of per capita medical travel CO_2 emissions, while Baixian and the border of Xiaopu Town and Si'an Town have formed obvious hot spots.

3.4.3 Travel CO_2 emissions reduction potential assessment

As mentioned, the CO_2 emissions beyond the acceptable time is the reduction potential of CO_2 emissions through the layout optimization of medical facilities. Based on GIS spatial analysis, 94.93 tons of CO_2 emissions from medical travel to level 3 medical facilities can be reduced, accounting for 57.65% of the current corresponding indicators. Similarly, 45.75 tons of CO_2 emissions from medical travel to level 2 medical facilities can be reduced, accounting for 80.42% of the current situation and 14.13 tons can be reduced by optimizing the layout of level 1 medical facilities, accounting for 70.37% of the current situation.

Tab.5 Carbon reduction potential space for optimizing the layout of medical facilities at all levels

Grade / Distance section	3	2	1
Acceptable time for medical travel (min)	25	12	12
AVG travel distance in acceptable time (km)	9.66	4.48	4.48
CO_2 reduction potential space (t)	94.93	45.75	14.13
CO_2 emissions from medical travel (t)	164.68	56.89	20.08
Percentage of CO_2 reduction potential in current travel CO_2 Emissions (%)	57.65	80.42	70.37

3.4.4 Discussion on the evaluating results

Taking medical facilities in Changxing as an example, this paper evaluated the effect of travel CO_2 emissions under the current layout from three aspects: total travel

CO_2 emissions, spatial distribution and CO_2 reduction potential, then puts forward the following three conclusions:

I. The layout of level 3 medical facilities is the key factor affecting the CO_2 emissions for medical travel, and should be fully considered in the stage of layout decision-making.

II. The supply level of medical facilities is an important factor affecting the medical travel of residents. As for Changxing, we can properly upgrade the service scale of medical facilities in Northwest and Hongqiao, as a low-cost way to optimize the distribution of medical facilities in combination with the current regional medical consortium system.

III. more than 50% of the current CO_2 emissions for medical travel can be reduced by optimizing the layout of the medical facilities. This shows that the potential of reducing CO_2 emissions by improving the service efficiency of medical facilities and shortening the average distance of residents' medical trips is very high.

4. CONCLUSIONS

This study combines the spatial interaction theory with the travel CO_2 emission measurement method, and then proposes a systematic method for evaluating the travel CO_2 emission effect under the layout of public service facilities based on residents' autonomous choice. This method can make up for lacking of data coverage at county level. This paper first simulates the residents' autonomous choice by constructing OD matrix of travel probability. Second, it extracts the characteristics including travel frequency, travel mode and acceptable time of travel using both questionnaires and GIS network analysis. Third, the total travel CO_2 emission under the layout of public service facilities is calculated based on the modified carbon emission measurement model. Finally, it analyzes the spatial distribution characteristics and carbon reduction potential of per capita travel carbon emissions using GIS spatial analysis in order to put forward suggestions for optimizing the layout of public service facilities under the low-carbon target.

This paper focuses more on providing a new perspective and a systematic method for low-carbon effects evaluation of public service facilities layout which can be developed in further studies. Since the choice of residents among different public service facilities is always related to the scale of facilities themselves and the distance between residences and facilities, the idea of establishing OD matrix of travel probability has universal adaptability. In the model built in this paper, the scale representation factor Sj can be changed according to the different type of public facilities. However, due to the subjectivity of residents' perception of travel distance and time where our travel behavior characteristic data mainly come from, there are limitations in our research. Therefore, further research will be conducted to seek for more accurate evaluation method.

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