The study of urban traffic modal splitting method based on MD model under the low-carbon mode

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Received 1 March 2014, www.tsi.lv

Abstract

Aimed at the problem of overly-simplify in the factors of travel cost in the traffic modal splitting method, built an Urban Traffic Modal Splitting Method Based on MD Model Under the Low-carbon Mode, to predict transportation share rate; Put forward four considerations such as the travel time, cost, safety and low carbon to describe the travel cost on the basis of the application of MD model; Gave the forecasting process of the prediction model and key variables algorithm, applied the model by the examples of DONGGUAN city. The results show that the urban structure of the transportation changed in DONGGUAN with rapid construction, development in traffic and implementation of transport policy, on the one hand, the travel occupies proportion of public transport (including conventional bus and rail transit) will increase significantly in the future, expected to reach more than 25% by 2020; on the other hand, motorcycle travel will gradually fade away.

Keywords: Transportation Planning, Low-carbon Transportation, MD model, traffic modal split

1 Introduction

Along with China's rapid economic development, our motorization process is accelerating. According to National Bureau of Statistics, the holding number of our civilian vehicles has already reached to 120,890,000 by the end of 2012. However, when our motorization process develops rapidly, it also brings a series of problems, such as traffic safety, environmental pollution, traffic congestion and energy shortage. The study on travel mode choice can be traced back to the development of the residents travel survey. With the analysis of the survey data on residents travel, more and more people begin to study residents travel, such as the research on the travel intentions, the influence factors of travel mode choice and travel mode prediction model. The study on the travel mode split makes the study on the urban road planning develop from three-stage to four-stage, which greatly promotes the study on modern urban road planning, and has become an important part of the four-stage method study on the urban road planning. Therefore, the study on the travel mode split has significant meaning for the urban road planning, and it is necessary to strengthen the research on this area.

The splitting models of the transportation means are mainly divided into two categories: one is the Aggregate Model based on the statistics, which includes the transfer curve model, the gravity model's transformation model and regression model. This model is simple and convenient with better application effect, but it needs to investigate a large number of statistical materials and has huge amount of work with difficult data collection [1-4]. Another is the Disaggregate Model based on the "random utility theory", which attempts to conduct modelling to the travellers in the possible choices on the problems, such as whether the individuals as the traffic behaviour decision unit travel, where to go, and what kind of transportation do they use and which path do they choose. Then it sums the sampling results of each person, and thus obtains the total traffic demand. Disaggregate model is the discrete choice model based on the maximum effect theory, among which the models with more application are the MNL model (Multinomial Logit Model), Probit model, NL model (Nested Logit Model) and Mixed Logit model [5-9].

Conventional transportation splitting forecasting model has the following defects:

1) Conventional transportation forecasting model does not consider low carbon travel chain

In the conventional mode choice model, traffic sharing rate usually chooses the Logit probability model, which distinguishes various means of transportation without considering the influence of the transportation that generates in the connection between various means of transportation on the residents travel mode choice in the actual traffic travel.

2) Conventional transportation forecasting model does not consider the extra charges caused by carbon emission

In the travel mode choice model, either aggregate model or disaggregate model generally considers the factors, such as travel time and costs in the travel fees, but under the broad environment, such as the global requirement of reducing the carbon emission and national

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strict control on the carbon emission in various industries, the additional costs caused by carbon emission are increasingly ignored. Adding carbon factor in the generalized travel costs will well control the carbon emission in the transportation in order to achieve a low-carbon transport requirement.

Aiming at the defects of the conventional mode choice model in the low carbon mode, it improves the travel mode choice model in the low-carbon mode based on that the four-stage prediction method introduces the low carbon factor and safety factor when building the modal split.

2 Basic principle of the MD model based on the low carbon mode

The basic principle of MD model main expresses by using the following concepts and assumptions [10]:

(1) Potential passenger transport demand Q_{ij}

Potential passenger transport demand means the total number of travellers of OD in all the travel possibilities between i to j, including the actual OD and possible generated OD, which does not consider the travellers' payment capacity, nor the ultimate realization of this travel need.

(2) Travel expense quantity S_{mij}

Travel expense quantity can also be called generalized cost, which means the travellers' money, time and energy consuming on the road. In the MD model, it assumes that travellers always choose the means of transportation on the principle of minimum travel expense, and consider the travel time, cost, safety, and low-carbon and other factors all have an impact on travel behaviour. The travel expense quantity indicated by logarithm shows as follows (curve relationship in Figure 1):

$$\ln(S_{mij}) = \ln\left[D_{mij}^{-1}(C_{mij} + vT_{mij} + Ca_{mij})\right]. \quad (1)$$

In this formula, S_{mij}, C_{mij} and T_{mij} respectively show the travel expense quantity, travel costs and travel time of OD to the means of transportation m between *i* to *j*; *v* is the value of travel time, that is the coefficient which converts the time unit into the monetary unit, and different types of travellers have different time value. This type mainly sets the income level and trip purpose as the discriminate criterion (in the MD model, it assumes that the time value conforms to the lognormal distribution, and the distribution parameters change over time); Ca- carbon factors, $Ca_m = v_c A_m$. In this formula, A_m is the m means of transportation's CO2 emissions per capital in per unit of time; v_c means the unit value of carbon; is the safety factor of the m means of transportation between the regions *i* to region *j* [11].

Security is the first factor in the travel choice. If the security of the travel mode cannot be guaranteed, this kind of travel mode will not be selected, so security can be considered to be independent with other factors. The D_{mij} safety factor is to use the numerical value between 0 ~ 1 to qualitatively characterize the safety, in which the smaller the numerical value is, the worse the security is. In travel expense quantity, An Wenjuan and other people use the reciprocal of the safety factor to represent the "security costs" that the residents choose to pay for some travel modes, and point out that safety, the larger the safety factor is, the smaller the travel expense quantity of this travel mode is.

(3) Travel utility u

In the MD model, travel utility does not consider the net effect of travel expense quantity is the benefit that the travellers expect to get regardless of the travel cost, so the travellers with different individual characteristics (mainly the travel purposes), their travel utilities are also different. The same as the value of travel time, MD model assumes that the travel utility also confirms to the lognormal distribution, and its distribution parameters do not change over time; meanwhile, it assumes that the standard deviation of travel utility equals to the standard deviation of travel time value.

(4) Boundary replacement ratio $v_{m,m-1}$

Figure 1 takes 5 means of transportation as example to depict the expense quantity curve of each mode of transportation, and the point that the travel expense quantities equal between transportation mode m and m-1 is the intersection of two curves, which is called boundary replacement ratio or demarcation point $v_{m,m-1}$, and can be derived by equation (1), see equation (2):

$$\ln v_{m,m-1} = \ln\frac{D_{(m-1)ij}(C_{mij} + R_{mij}^{m}) - D_{mij}(C_{(m-1)ij} + R_{(m-1)ij}^{m})}{D_m T_{(m-1)ij} - D_{(m-1)ij}T_{mij}}. \quad (2)$$

In this formula, $v_{m,m-1}$ is the boundary replacement ratio of transportation mode m and its nearest transportation mode m-1; others are as the above.

On the boundary replacement ratio, the expense quantities are equal on adopting the m transportation mode and the nearest m-1 transportation mode, that is:

$$C_{mij} + v_{m,m-1}T_{mij} = C_{(m-1)ij} + v_{m,m-1}T_{(m-1)ij}. \quad (3)$$

According to the equation (2) of the boundary replacement ratio, it can reckon the time value section of different means of transportation, and calculate the selected portion of each mode.

(5) Manifest rate of potential demand R_{mij}

In the MD model, according to its basic assumption, the travel utility and time value of the travellers are uncertain. Travellers choose the transportation mode with minimum travel expense by considering their own time value. Only when travellers' travel utility is greater than the expense quantity of the selected travel mode, will the travel demand be implemented. In the MD model, after the implementation, the potential passenger transport demand quantity is the actual demand quantity, and the ratio between these two is called the manifest rate of potential demand:

$$R_{mij} = \frac{q_{mij}}{Q_{ij}} . \quad (4)$$

In this formula, R_{mij} is OD's manifest rate of potential demand on the transportation mode between *i* to *j*; q_{mij} and Q_{ij} are respectively the actual and potential travel demand quantity of OD to the transportation mode between *i* to *j*.

When the travel expense quantity of the transportation mode m is the minimum expense quantity, it will be chosen by travellers; and only when the travellers' travel utility is greater than the expense quantity of transportation mode m, the travel will be achieved. Therefore, the manifest rate of potential demand can be obtained by calculating the volume of two probability distribution points of the time value and utility, shown as the formula (5).

$$R_{mij} = \int_{\ln S'_{mij}}^{+\infty} f(\ln u) \int_{\ln v_{m,m-1}}^{\ln v_{m,m+1}} f(\ln v) d(\ln v) d(\ln u) . \quad (5)$$

In formula (5), $f(\bullet)$ is the probability density function of normal distribution.

Travellers have two options of transportation modes on the mini car and regular bus. The intersection of the expense quantity curves of min car and regular bus is v_1, if the travellers' time value is higher than v_1, they will choose the mini car; otherwise, they select the regular bus. Secondly, after choosing travellers' own travel modes, the travel will actually occur only when the travel utility is greater than the expense quantity. By calculating the volume of the curve part that effectiveness of various modes of transportation exceeds the expense quantity, the ratio of the actual demand manifested by the ultimate potential demand of the regular bus and mini car can be obtained, namely, the implementation rate of the potential transport demand. The ratio of the actual demand manifested by potential demand of regular bus is the volume of two combination points of probability distribution abc of the time value and utility, while that of the mini car is the volume of bcd.

3 MD models prediction method on the transportation mode under the low carbon mode

3.1 PREDICTING THOUGHT

Based on the basic principle of MD model and formula (4), it predicts the actual demand of the transportation mode m in the t year can be obtained according to its potential travel demand and the manifest rate of potential demand, that is:

$$q_{mij}^t = Q_{ij}^t \left(R_{mij}^{'}\right)^t . \quad (6)$$

The probability of selecting the transportation mode m, namely the travel demand proportion occupied by transportation mode m, can be shown as:

$$P_{mij}^t = \frac{q_{mij}^t}{\sum_m q_{mij}^t} = \frac{Q_{ij}^t (R'_{mij})^t}{\sum_m Q_{ij}^t (R'_{mij})^t} = \frac{(R'_{mij})^t}{\sum_m (R'_{mij})^t} . \quad (7)$$

Therefore, the key of predicting the sharing rate of transportation mode m is to obtain the manifesting rate of potential demand of transportation mode m.

3.2 MODAL CALCULATION THOUGHT

Currently, researches on the MD model calculation method are seldom published at home and abroad, and there is basically no mature achievement that can be directly applied. The potential passenger transport demand in the MD model itself is a relatively abstract concept, which is an invisible, intangible thing in the social and economic phenomena. Therefore, it cannot be obtained through investigation and statistics, while the manifested passenger capacity can get a more accurate value by observation and investigation. In this paper, the calculation of the potential passenger transport demand between the traffic zones is achieved by twice applying the relativity principle on two levels.

The key for the model solution is the solution of four variables of time value, travel expense quantity, travel utility and potential passenger transport demand.

(1) Estimation of the travel time value

The first thing to use the MD model to predict is to make sure the status quo and future value of the time value on the area of the research object. There are many factors that affect the travel time value, but they are mainly connected with the travel purpose and the level of household income. According to the correlation researches of the World Bank on the traffic assessment, the considerations and computational methods of each trip purpose are shown in Table 1:

TABLE 1 The considerations and computational methods of each trip purpose

Travel type and purpose	Consideration	Computational method
Working trip	Traveler's labour charge	1.29×salary/hour
Business trip	Traveler's labour charge	1.29×salary/hour
Commuting and other working trips	Empirical observation	0.2×family income/hour

Calculation on the time value of per person with various vehicle models shows as formula (8):

$$V_{person}^{k} = \frac{1.29*W*QT_{work}^{k} + 0.2*H*QT_{unwork}^{k}}{QT_{work}^{k} + QT_{unwork}^{k}} . \quad (8)$$

In the formula (8), V_{person}^{k} - the time value per person per time of the motor vehicle typed K, Yuan/person/hour;

W - the average hourly earnings level, Yuan/hour;

H - the average hourly family income level, Yuan/hour;

QT_{work}^{k} - the turnover of the residents' working trip, person/minute;

QT_{unwork}^{k} - the turnover of the residents' nonworking trip, person/minute;

On the consideration of allocating the model parameters, the parameter of the time value has more important role on choosing the rail rapid transit system for the passengers. The higher the unit time value is, the more the passengers tend to choose the rapid system to complete travel.

For the time value of future years, due to the rising tendency of the time value, and the lower increase of the time value than that of the GDP (Because people has relatively prior tendency on the improvement of the lifestyle other than the travelling expenses as well as the increase of the expend on education during the process of income incensement), based on the regression analysis of historical data and combine the experience, if assuming the variance and base year of the time value in the future years are the same, its mean value can be calculated by the following formula:

$$v_t = v_j \sqrt{\frac{GDP_t}{GDP_j}} . \quad (9)$$

In this formula: v_t is the mean value of the time value for future years; v_j is the mean value of the time value for base years; GDP_t is the future gross domestic product; GDP_j is the gross domestic product for the base years.

(2) Estimation of the travel expense quantity

According to formula (1), the travel time value, travel time and low carbon factors can be obtained by RP / SP [12] investigation and research results, the calculation of the travel expense C_{mij} in the travel expense quantity in this paper uses the formula (10).

$$C_{mij} = R_{mij} \times \frac{L_{mij}}{n} . \quad (10)$$

In this formula: R_{mij} is the freight rate of transportation mode m, Yuan/ (person • km), the mini car's travel expense is equal to the corresponding road transport cost plus fuel cost; L_{mij} is the running mileage of transportation mode m, km; n is the number of calculation, the passenger car gets 1, while the mini car gets the average real carrying number.

(3) Calculation of the travel utility

Using the computational formula of the manifest rate of potential demand in the MD model, that is $R_{mij} = \frac{q_{mij}}{Q_{ij}}$, it can get:

$$Q_{ij} = \frac{q_{1ij}}{R_{1ij}} = \frac{q_{2ij}}{R_{2ij}} = ... = \frac{q_{mij}}{R_{mij}} . \quad (11)$$

Putting the formula (5) into formula (11), the $q_{1ij}, q_{1ij}, ..., q_{mij}$ in the equation can be obtained by actual passenger travel statistics, probability density function form of the time value and utility is known, the mean value and variance of the time value can be estimated by the aforementioned method. If assuming that the variance of the utility is same as the time value, then only the variance $u_{\ln u}$ of the utility is unknown; but it can get C_m^2 equations from the formula (11), and the C_m^2 equations summation can get C_m^2 utility average solution. Since the average value of a number of data and sum of squares of deviations in the individual data are the minimum, it takes the averaging approach to confirm the mean value of utility and finally the utility average adopts the average value in order to be better fitted with the current situation, namely:

$$u_{\ln u} = \frac{1}{C_m^2} \sum_{k=1}^{C_m^2} (u_{\ln u})_k . \quad (12)$$

(4) Calculation of the manifest rate of potential demand

Respectively putting the calculated time value, travel utility and travel expense quantity of the base years and forecasting years into the formula (5), it can get the status quo R'_{mij} and predicted value $(R'_{mij})^t$ of OD for the manifest rate of potential demand between each transportation mode.

4 Analyses of examples

This paper takes Dongguan City as an example to predict the urban means of transportation under the low carbon demand. In 2009, Dongguan City did the research on residents traveling (RP survey) and residents traveling intention (SP survey) directing at the adjustment of the Rail Transit Planning. The research content includes the personal socio-economic characteristics survey (gender, age, occupation, education and income) , family socio-economic characteristics (home address, family population, family income, number of family cars and bikes), activity chain survey data (objectives, start time, trip distance, travel modes, travel costs, whether needs transfer) and residents' travel intention choice under the assumptions of the completion of various modes of rail transit network, site settings and different levels of fares. The number of effective samples of this survey is about 6,000, which distributes in the 32 towns of the whole city. These data gets settling and applying in the Rail Transit Planning Adjustment in Dongguan City.

It is known that, the total area of the administrative region in Dongguan City is 2465 km2. According to the sixth census, in 2010 the city's permanent resident population is 8.22 million, of which the household population is 1.8177 million. This paper will divide Dongguan City into four major traffic areas, 55 traffic zones. Based on the survey, the means of transportation in Dongguan City are mainly in the way of private and individual transportation mode. In 2010, the proportion of each transportation mode is: walking 25.9%, private cars 25.2%, bikes 15.0%, buses 15.2%, motorcycles 14.2%, taxis 1.9%, company cars 0.4%, others 2.3%.

Compared with the survey data in 2001, 2005, 2008 and 2010, the travel time and travel distance status quo remain the same, and have no larger changes, as shown in Table 2.

TABLE 2 The average travel time consumption of different transportation of DongGuan City

Year \ Transportation mode	Walking	Bicycle	Bus	Taxi	Motorcycle	Company car	Private car	Total
2001	17.1	18.7	31.2	19.4	20.5	23.4	21.0	19.3
2005	17.1	17.2	28.2	24.1	19.1	24.5	27.7	19.7
2008	15.5	18.4	35.0	24.8	18.0	27.8	24.4	20.0
2010	19.4	20.8	37.1	30.1	18.4	29.1	25.4	24.1

By calculating, the parameters of the unit time value in the main characterized year predicting by the passenger traffic in Dongguan City, as shown in Table 3.

TABLE 3 The time value per people of the characterized year

Year	2020	2022	2024	2027	2029	2031	2042	2044	2046	Prospect
VOT(Yuan/Person Hour)	19.7	21.4	22.3	23.1	23.7	24.1	25.6	25.9	26.1	27

According to the data of residents travel characteristics (travel strength, consumption and trip purpose) and major road traffic volume, it gets the basic data of travel time and travel costs of all modes of transportation in the base year. The MD model which is built by applying the low carbon traffic mode divides the residents travel modes within the scope of Dongguan city. Setting 2020 as the transportation forecast characterized year, the results are shown in Table 4.

From the predicted results, with the rapid traffic construction, development as well as the improvement and implementation of the traffic policies in Dongguan city, its structure of travel mode has changed, especially the further implementation of the ban on motorcycles greatly develops the call for public transport and increase of the demand on low-carbon, which predicts that the share of Dongguan motorcycle travel mode has decreased from 14.2% in 2010 to 3.5% in 2020 in the total travel modes; the share of public transport mode has increased from 15.2% in 2010 to 25.1% in 2020; the change of the share of the company car and other cars is less significant.

TABLE 4 The urban traffic modal splitting results in the domain of DongGuan City

Transport mode \ Year	2010	2015	2020
Walking	25.9%	26.7%	28.6%
Bicycle	14.9%	15.3%	15.8%
Motorcycle	14.2%	10.5%	3.5%
Conventional public traffic	15.2%	16.1%	14.8%
Rail transit	0.0%	3.8%	10.3%
Taxi	1.9%	2.1%	2.3%
Mini car	26.2%	24.5%	23.8%
Company car	0.4%	0.3%	0.3%
Others	1.3%	0.7%	0.6%

5 Conclusions

Based on the basic principles of the MD prediction model, this paper considers the low-carbon policies impact on residents travel choice and depicts the travel costs by using the factors of travel time, cost, safety, and low-carbon to propose the MD forecasting model split by urban transport mode under the low-carbon mode. It puts forward the model calculation process and has applied the improved model. The application results show that the prediction result has some rationality. However, the mean value of the travel utility defaulted by the MD model does not change along with time, which still has a certain gap with the actual situation, and needs to be further improved.

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