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An estimation method of OD matrix in non-congestion ring expressway

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Abstract

In order to obtain the real-time traffic flows between on-ramps and off-ramps of the ring expressway, a model to estimate the OD(origin-destination) matrix with consideration of the structural characteristics of the ring expressway is proposed in this paper.The ring expressway is looked as a loop network, without considering traffic congestion,the distance fromthe on-ramps to off-ramps that drivers may choose is not exceeding 1/2 of the loopperimeter. According to this principle, we use on-ramps' flows to express mainline sections' and off-ramps' flows. These expressions form the simultaneous equations which can be solved with Gaussian Elimination, and the flow proportions between on and off-ramps (OD matrix) can be achieved. The propose method is applied to Xi'an Ring Expressway, the OD matrix is extracted from the estimated flow proportions between on and off ramps, and is compared with the actual survey. The model is verified to be feasible.

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*Keywords:*traffic engineering; ring expressway; one-way loop network; OD matrix; estimation model

1. Introduction

The dynamic OD matrix between the entries and exits of expressways is the most basic input data of intelligent traffic management systems such as on and off-ramps control, traffic information service, emergency response and real time traffic management(Jiao and et al. 2005). Approaches to motorway OD estimation aim to address the rapidly changing the effects of traffic management strategies(like speed control or ramp metering)(Camus 1997). At present, the model of using the traffic data of expressway sections and ramps to estimate the OD matrix is widely used(Chang 2009). The main estimation models are Generalized Least Squares method(Lin and et al. 2003), Kalman Filter method(Chang and et al. 2003), Neural Network Prediction method(Lorenzo and et al 2010), and Gray Markov Chain method(Du and et al. 2009). In the literature(Kikuchi, 2000), The neural network was designed in

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such a way that its weights represent the ramp-to-ramp volume expressed as a proportion of the inflow(origin) to each outflow(destination).Nancy et al.(1989) used the most basic least squares method. The least squares model was first used to estimate the static OD matrix. Cascade (1984)and Bell(1991) used the least squares estimation method to estimate the OD matrix of the road network.The Kalman filtering method originates from modern control theory and is suitable for the real-time estimation of freeway OD matrix. Although the literature(Cremer M 1987) considers the constraint problem, the proposed method cannot achieve good results.

The above methods have obvious defects when used to estimatethe OD between on and off-ramps of the ring expressway: (1) To ensure the uniqueness of the estimation OD matrix, the priori OD must be need to supplement the insufficient of the survey data. For the ordinary expressway, history OD data can be obtained through toll stations. However, there are no toll stations on the ring expressway around the city. (2) The model is complex, the solution is difficult, and the non-definite solution often appears. (3) It takes a lot of time and costs to surveythe traffic flow.Compared to the ordinary expressway, the OD matrix of the ring expressway has obvious characteristics because of its ringlikeand closed property. It is necessary to study the estimation method that is suitable for the characteristics of the ring expressway.

Thering expressway is usually a ring, so we use the loopto represent the ring expressway around the city in this paper. The clockwise direction of the loop is defined as the downward direction, and the anticlockwise direction is the upward direction. The upward main lines and on and off-ramps constitute the upward system of the ring expressway, and downward main lines and on and off-ramps constitute the downward system. Each system, which is called one-way loop network, can be studied separately.

2. OD estimation model of simple one-way loop network

Fig.1 shows the downward system of the ring expressway with only i1, i2 on-ramps and o1, o2 off-ramps. The loop is divided into 8 sections by ramps.

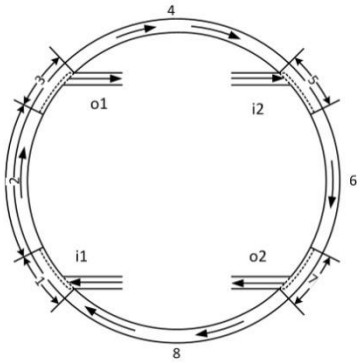

Fig. 1. Single one-way loop network.

The traffic flow accessing the loop network from any on-ramp will leave out from off-ramps, that is, the flow of on-ramps i1 and i2 are equal to flow of off-ramps o1and o2, as:

$$q_{i1} = q_{i1,o1} + q_{i1,o2} = a_{11} \cdot q_{i1} + a_{12} \cdot q_{i1} \tag{1}$$

$$q_{i2} = q_{i2,o1} + q_{i2,o2} = a_{21} \cdot q_{i2} + a_{22} \cdot q_{i2} \tag{2}$$

where:

q_{i1}, q_{i2}: Respectively for flow of on-ramp i1,i2.

q_{o1}, q_{o2}: Respectively, flow of off-ramp o1,o2.

a_{11}, a_{12}: The ratio of flowsaccessing fromon-ramp i1to off-ramp o1 and o2, $a_{11}+a_{12}=1$.

a_{21}, a_{22}: The ratio of flowsaccessing fromon-ramp i2 to off-ramp o1 and o2, $a_{21}+a_{22}=1$.

Let $OD=\begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{bmatrix}$, then OD is the ramp-selectionrate matrix, it is the OD matrix of the ring expressway.

Let $D_1=[a_{11}, \quad a_{21}]^T, D_2=[a_{12}, \quad a_{22}]^T, O=[q_{i1}, \quad q_{i2}]$

then:

$$q_{o1}=a_{11}\cdot q_{i1}+a_{21}\cdot q_{i2}=O\cdot D_1 \tag{3}$$

$$q_{o2}=a_{12}\cdot q_{i1}+a_{22}\cdot q_{i2}=O\cdot D_2 \tag{4}$$

The flow of each section of mainline can be described by the flowsof on and off-ramps, that is:

$$q_1=q_2=q_{i1}+q_7=q_{i1}+q_8=q_{i1}+a_{21}\cdot q_{i2} \tag{5}$$

$$q_3=q_4=a_{12}\cdot q_{i1} \tag{6}$$

$$q_5=q_6=q_{i2}+q_3=q_{i2}+q_4=q_{i2}+a_{12}\cdot q_{i1} \tag{7}$$

$$q_7=q_8=a_{21}\cdot q_{i2} \tag{8}$$

In the formulas:

$q_1, q_2, \ldots, q_8$: Flows of the mainline section 1 to section 8.

a_{11}, a_{12}, a_{21}, and a_{22} can be obtain by the expression (3), (4), (6), and (8), so that the ODmatrix on the loop network can be achieved.

3. OD estimation model of complex one-way loop network

When there are many ramps on the loop network, the distribution of the entrances and exits and assignment of the traffic flow will become complicated. The most common layout of the entrances and exits of the one-way loop with multi-ramps is shown in Fig.2.

Considering the psychology of the driver choosing the exit on the ring expressway, the off-ramp with the smallest mileage to his or her destination should be at the top of priority list. So we assume that without considering congestion, the distance from the on-ramp to the off-ramp selected by a driver will not exceed 1/2 of the loop length. If not, the driver will choose the other direction of the loop, its mileage is shorter and the fuel consumption is less.

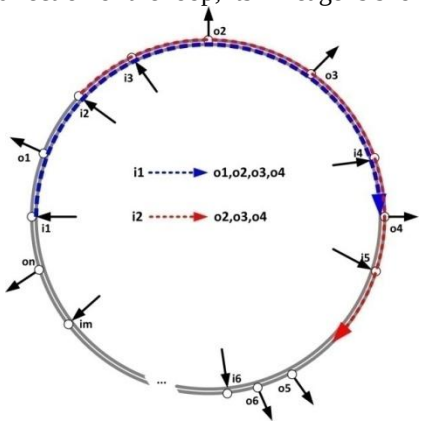

Fig. 2 Complex loop network with multi-ramps

at this time:

$$OD = \begin{bmatrix} a_{11} & a_{12} & a_{13} & \dots & a_{1n} \\ a_{21} & a_{22} & a_{23} & \dots & a_{2n} \\ a_{31} & a_{32} & a_{33} & \dots & a_{3n} \\ \dots & \dots & \dots & \dots & \dots \\ a_{m1} & a_{m2} & a_{m3} & \dots & a_{mn} \end{bmatrix} = [D_1, D_2, \mathrm{D}_3, \dots, D_n]$$

$$D_n = [a_{1n}, \mathrm{a}_{2\mathrm{n}}, \mathrm{a}_{3\mathrm{n}}, \dots, \mathrm{a}_{\mathrm{mn}}]^T$$

$$O = [q_{i1}, q_{i2}, q_{i3}, \dots, q_{im}]$$

Same as the simple loop network, the traffic flow of each off-ramp, main line and its every section in the complex loop network can be expressed by the traffic flow of on-ramps. These expressions form the simultaneous equations which can be solved by Gaussian elimination method. The solution of the simultaneous equations is the OD matrix of the complex loop network. This OD matrix describes the traffic demand of the loop network at the sampling period. The OD matrix at the next sampling period is continuous with the prior OD. For example, the flow exited form off-ramp j in period k+1 can be expressed as:

$$q_{oj}(k+1) = O(k+1) \cdot D_j(k) \tag{9}$$

$$D_j(k) = [a_{1j}(k), \quad a_{2j}(k), \quad \dots, \quad a_{mj}(k)]^T \tag{10}$$

$$O(k+1) = [q_{i1}(k+1), \quad q_{i2}(k+1), \quad \dots, \quad q_{im}(k+1)] \tag{11}$$

where $q_{im}(k+1)$ is the traffic flow entering the main line from on-ramp im during the sampling period, pcu/h.

By the same token, the traffic flow in any section of the main line in the loop network can be linearly expressed by the coefficients in O matrix and OD matrix, that is, it can be represented by traffic flow of several on-ramps.

4. Example

Xi'an Ring Expressway is a two-way and six-lane highway. The uplink and downlink are completely isolated. The maximum design speed is 120km/h. We select the downlink as an example.

The downlink of Xi'an Ring Expressway includes 28 on-ramps and 28 off ramps, as shown in Fig.3.

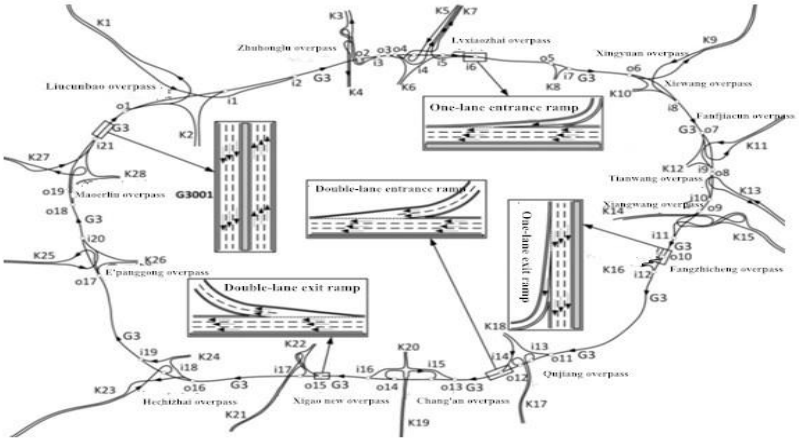

Fig. 3 Ramp distribution of downlink of Xi'an Ring Expressway

In order to analyze conveniently, the ramps which have the same exit were merged into one ramp. The simplified ramp distribution is shown in Fig.4.

According to the assumption in section 3 of the paper, the distance from the on-ramp to the off-ramp selected by the driver is not exceeding 1/2 of the loop perimeter, the OD matrix of Table 1 is obtained. The OD matrix expresses flows between on-ramps and off-ramps. For example, the first line is the 0-1 line vector which means the traffic flows entering from on-ramp i1 will flow out from the off-ramp o2, o3, o4, o5, o6, o7, o8, o9, and o10.

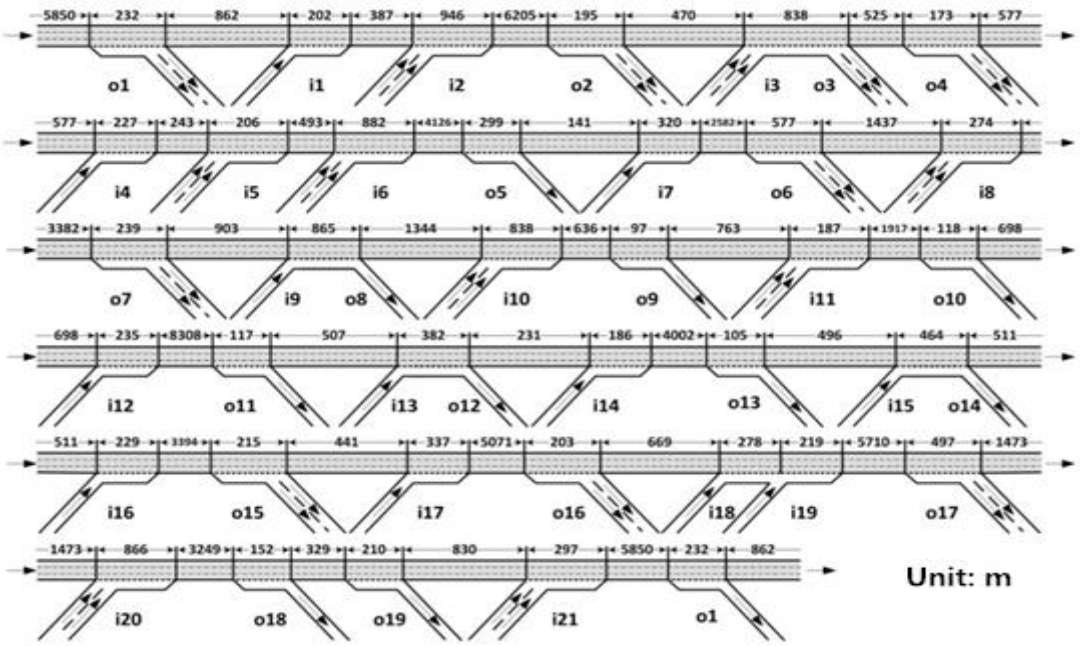

Fig.4 Simplified ramp distribution of downlink of Xi'an Ring Expressway

Table 1 0-1 OD matrix of downward traffic flow

	o1	o2	o3	o4	o5	o6	o7	o8	o9	o10	o11	o12	o13	o14	o15	o16	o17	o18	o19
i1	0	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0
i2	0	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0
i3	0	0	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0
i4	0	0	0	0	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0
i5	0	0	0	0	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0
i6	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0
i7	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	0	0	0
i8	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	0	0	0
i9	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	0	0
i10	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	0	0
i11	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	0	0
i12	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1

i13	1	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1
i14	1	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1
i15	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1
i16	1	1	1	1	0	0	0	0	0	0	0	0	0	0	1	1	1	1
i17	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	1	1	1
i18	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	1	1
i19	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	1	1
i20	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	1
i21	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0

When the traffic density on the mainline does not reach the congestion value, the speed of each road section can be replaced by the average speed of the mainline. At this period, the mean value of the traffic flow of each on-ramp and off-ramp is used to estimate the OD matrix, results are shown in Table 2.

Table 2 OD matrix of Xi'an Ring Expressway (%)

	o1	o2	o3	o4	o5	o6	o7	o8	o9	o10	o11	o12	o13	o14	o15	o16	o17	o18	o19
i1	0	4.7	6.2	12.5	9.3	17.3	22.4	8.4	11.4	7.8	0	0	0	0	0	0	0	0	0
i2	0	4.4	5.6	12.7	8.8	18.6	23.5	9.2	11.4	5.8	0	0	0	0	0	0	0	0	0
i3	0	0	4.1	5.2	5.3	7.8	16.2	6.1	9.4	7.4	11.3	10.7	9.4	7.1	0	0	0	0	0
i4	0	0	0	0	7.4	10.4	17.5	7.3	16.5	11.3	11.7	6.5	6.3	5.1	0	0	0	0	0
i5	0	0	0	0	5.3	11.2	15.3	7.2	14.2	16.3	9.5	6.7	7.1	7.2	0	0	0	0	0
i6	0	0	0	0	5.1	8.6	14.3	7.2	14.6	13.5	9.6	7.3	6.2	5.7	7.9	0	0	0	0
i7	0	0	0	0	0	5.3	11.3	7.3	13.5	11.2	14.2	9.3	11.4	7.4	16.4	6.2	0	0	0
i8	0	0	0	0	0	0	6.1	6.2	10.5	12.6	13.5	12.6	11.6	7.5	11.1	8.3	0	0	0
i9	0	0	0	0	0	0	0	3.3	4.7	5.2	8.1	6.7	11.5	7.3	20.1	22.6	10.5	0	0
i10	0	0	0	0	0	0	0	0	3.4	5.6	11.3	12.4	13.5	12.4	16.5	15.3	9.6	0	0
i11	0	0	0	0	0	0	0	0	0	7.3	14.6	13.4	12.7	11.5	17.4	13.2	9.9	0	0
i12	0	0	0	0	0	0	0	0	0	0	10.2	8.5	11.3	11.4	17.2	17.4	9.4	9.3	5.3
i13	15.1	0	0	0	0	0	0	0	0	0	0	3	5.2	8.3	14.5	18.2	15.2	12.3	8.2
i14	14.2	0	0	0	0	0	0	0	0	0	0	0	5.2	8.3	15.9	17.8	14.3	14.5	9.8
i15	13.5	0	0	0	0	0	0	0	0	0	0	0	0	5.6	15.4	17.8	17.3	17.3	13.1
i16	16.4	11.6	7.2	9.5	0	0	0	0	0	0	0	0	0	0	5.2	15.3	14.5	11.2	9.1
i17	16.3	14.6	13.5	8.2	6.4	0	0	0	0	0	0	0	0	0	0	10.5	14.4	8.3	7.8
i18	16.5	17.3	12.4	12.5	5.6	6.3	0	0	0	0	0	0	0	0	0	0	6.4	12.3	10.7
i19	20.7	14.4	11.6	14.6	5.3	7.2	0	0	0	0	0	0	0	0	0	0	5.1	11.5	9.6
i20	13.6	14.6	8.4	9.6	6.2	10.5	11.7	6.3	6.1	0	0	0	0	0	0	0	0	7.3	5.7
i21	7.3	12.5	9.3	12.3	9.4	13.6	15.3	8.7	7.5	4.1	0	0	0	0	0	0	0	0	0

Result analysis:

In Table 2, the row data is the proportion of on-ramps traffic flow allocated to off-ramps, and the sum of the data in each row is 100%. The column data is the traffic composition of the exit ramp. It is obvious that the total proportion of traffic volume to off-ramp O_1, O_7, O_{15}, O_{16} are more greater, the data respectively are 133.6, 153.6, 157.6, 162.6, 126.6, and to off-ramp O_5, O_8, O_{19} are smaller, they are 74.1, 77.2, 79.3. It is consistent with the survey.

5. Conclusion

The paper proposes the method to estimate the OD demand matrix of the ring expressway, the method can calculate the flow allocation proportion of on-ramps to off-ramps only by using the flows of on-ramps. Compared with traditional OD estimation model, it has a clear logical structure with fewer variables and less complexity. Moreover, the model only needs entrance-ramp traffic flow, no road traffic flow, and traffic survey workload and costs are significantly reduced. The hypothesis that the distance from the on-ramp to the off-ramp driver choose does not exceed 1/2 of the total length of the expressway is reasonable only when the traffic has no congestion. In the congestion condition, how to make full use of the unique physical structure of the loop network to estimate the real-time dynamic OD matrix needs further study.

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