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Research Review of Origin-Destination Trip Demand Estimation for Subnetwork Analysis

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Abstract

OD matrix is one of the important dates for traffic planning, management and controlling, and OD demand estimation is an advanced technical method to gain the OD matrix dates. When the range of study focus on the interest of the planners, trip demand estimation for subnetwork becomes necessary. This paper summarizes and compares existing methods for subnetwork OD matrix estimation, including static and dynamic estimation methods. Different models and algorithms are discussed and the realistic significance of every technique will be revealed. Hot points of subnetwork demand estimation in future also will be given in the paper.

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1. Introduction

At present, estimating the unknown OD matrix via certain observed vehicle counts or some estimated traffic counts has become an efficient and short-period technique to gain OD matrix, followed by various models correspondingly. Since the 70 s, lots of methods to estimate OD matrix which based on observed or estimated counts have been proposed, such as integrated simulation model which only requires connected dates, maximum entropy(EM) model based on maximum entropy principle, generalized least squares (GLS) model based on least square principle, maximum likelihood (ML) model based on maximum likelihood principle and gravity model. While in some planning practices, researchers tend to analysis and evaluate the network they interested in, thus the subnetwork has often been used. How to construct a subnetwork OD matrix which coincides with reality as much as possible has become the research target of many planners.

This paper firstly carries on the analysis of the most difficult problems for subnetwork demand estimation methods, then the research status and the existing problems will be summarized from static and dynamic estimation methods respectively, involving the models and algorithms. Finally subnetwork demand estimation of future research tendency will be discussed.

2. Difficulties

Subnetwork is a local, closely connected part of the global network, which shares some common spatial or physical features. In the transportation field, one almost always evaluates and analyzes network flows at an abstracted subnetwork level. It is straightforward to identify and form a subnetwork, extracting the corresponding demand pattern or distribution from its full-size counterpart and ensuring that the result of a network flow evaluation conducted in the subnetwork will be consistent with the full-size result are far more difficult task. The difficulties are mainly embodied in two aspects.

Firstly, methods to estimate the OD matrix are mostly based on link-level counts which can be estimated via prior matrix and also can be detected by observation equipment. Due to the measurement error of link flow and synchronism of observation time, the deviation of observed link value is inevitable, i.e. $\sum_{A \in E} v_a = \sum_{A \in E} v_a \neq 0$, thus estimating subnetwork OD matrix utilizing the link counts may lead to great error.

Secondly, subnetwork OD flows is of variability. Like the traditional OD matrix estimation, because of the unpredictability of OD matrix, the precision of estimated OD matrix cannot be obtained directly but by the proportion of observed flow and distributed flow indirectly. In addition, to guarantee the reliability of subnetwork OD estimation is of importance, which not only require accuracy standard, but also that the travel demand analysis in the subnetwork would closely mimic full-network modeling results, that is to match the city land utilization layout. How to improve the accuracy and reliability of subnetwork OD matrix estimation is another difficulty.

3. Methodology

3.1. Static origin-destination trip demand estimation for subnetwork

Generally speaking, OD matrix estimation aims to find a solution closed to real matrix from feasible solution space which meets traffic flow constraints. Static method tend to solve the problem from a macroscopic point. While OD matrix estimation are probably an infinite-solution problem, thus the primary task is how to construct a model with the nonuniqueness solution through designing optimization goal and constraint conditions. When taking the traffic counts which from different technique methods as the input, we can analyse the problem from two aspects: observed traffic counts from the detecting coil arrangement and estimated link-level counts from
traffic assignment, while the latter can be classified to the fixed OD matrix estimation and elastic OD matrix estimation.

(1) Detecting coil arrangement and integrated simulation model

The domestic and international research about the detection coil layout method is mainly divided into two categories: one is based on the estimation of traffic flow and the other based on OD estimation. The second method is used to solve the OD estimation problem which strives to cover the whole road OD quantity using smaller sample size from the network traffic flow perspective.

XU Tiandong (2009) invented a ‘closed ring’ test coil layout mode, set up a Monte Carlo integrated simulation model for network traffic and OD estimation of local area. This method could use of the limited traffic acquisition equipment to work out all road traffic counts and network OD matrix of local area. We do not have to construct any model and algorithm, while the vehicle path and each intersection turn rate must be get in advance, the latter can be gained through calculation or regular investigation. This method can grasp the city road network traffic running status comprehensively with well reliability, but the region is more big, integrated simulation process becomes longer.

(2) Fixed origin-destination trip matrix estimation

To meet the requirement of uniqueness, static subnetwork trip matrix estimation often use the maximum entropy principle. Some methods related will be compared as follows.

Rossi et al. (1989), Janson (1993), Larsson (2002), Bar-Gera (2006) proposed an method based on maximum entropy principle, that is to produce a most likely, unique path flow in the full network by an entropy-maximizing user-equilibrium traffic assignment algorithm, and then aggregating corresponding path flows to form a subnetwork trip matrix.

The maximum entropy user-equilibrium (MEUE) problem could be written as follow

\[
\begin{align*}
\text{maxE} & \left( h \right) = - \sum_{p \in N_0} \sum_{q \in N_d} \sum_{r \in R_{pq}} h_r \cdot \log \left( \frac{h_r}{d_{pq}} \right) \\
\text{s.t.} & \sum_{r \in R_{pq}} h_r = d_{pq} \ \forall p \in N_0; \forall q \in N_d \left( p \right) \\
& \sum_{r \in R_{pq}} h_r = d_{pq} \ \forall p \in N_0; \forall q \in N_d \left( p \right) \\
& h \geq 0
\end{align*}
\]

where \( h_r \) represents the flow along route \( r \in R_{pq} \) from origin \( p \) to destination \( q \), \( d_{pq} \) is the flow of travelers in units of vehicles per hour from each origin \( p \) to every destination \( q \), \( f^*_a \) denotes the vector of total link flows. There are several solution approaches for the model above, such as a link-based computational procedure using successive stochastic user-equilibrium approximations and dual methods. Due to the probability of leading to nonunique dual solutions and creating a convergence problem, the dual method is replaced by the primal method in this case. The result of this method is a fixed matrix.

An another method to estimate the demand of subnetwork was proposed by Chixie in 2010, which also utilized the entropy maximization principle. Unlike the model above which must store and manipulate path flows from the full network, this method requires only a link flow pattern from traffic assignment in the full network. The ME problem could be constructed as follow:

\[
\begin{align*}
\max & - \sum_{rs} \left( x_{rs} \ln x_{rs} - x_{rs} \right)
\end{align*}
\]
where trip rate \( x_{rs} \) is defined as

\[
x_{rs} = \sum_{rs} f_{rs}^{i^*} \quad \forall r \in R, s \in S
\]

In this case, Chi adapts the Frank-Wolfe algorithm to solve the ME problem, and in order to avoid path enumeration and relax the computational difficulty, the column generation approach is adopted here. Just as the result of the prior model, this method also leads to a fixed matrix.

If the research area would not change much or we only want a short-period estimation, using fix origin-destination trip matrix estimation can introduce an accurate matrix relatively. While when changes occurred in some roads obviously or we want a long-period estimation, this method cannot achieves the high accuracy, even can leads to a big error. We can categorize OD trips into four group: (1) internal-internal trips; (2) internal-external trips; (3) external-internal trips; (4) external-external trips. When we alter some characters of some roads within subnetwork, traffic route may change within the subnetwork, even do outside the subnetwork. So even such method provided some criterions for subnetwork demand estimation, they may introduce a serious mistake--loses important global diversion/attraction effects which occur due to local changes. Just because of this, a fixed OD matrix may not sufficiently reflect the variable nature of subnetwork OD flows.

(3) Elastic origin-destination trip matrix estimator

Chi(2011) raised a maximum entropy-least squares estimator which based on elastic demand formulations where the demand function between pairs of boundary nodes depends on the equilibrium travel time between them. There are two principles in this method. The first is that the OD flows are distributed according to the maximum entropy theory, the second is to estimate the given elastic demand function of each OD pair.

The combination of maximum entropy and least squares results in the following optimization model:

\[
\begin{align*}
\min_{f,b,e} \sum_i \sum_{rs} (x_{rs}^i \ln x_{rs}^i - x_{rs}^i) + w \sum_i \sum_{rs} \left( d_{rs} \left( t_{rs}^i b_{rs}, e_{rs} \right) - x_{rs}^i \right)^2 \\
\sum_{rs} \sum_k f_{rs}^{e^i} \delta_{a,k}^{rs} = v_a^i \quad \forall a \in A, i \in I \\
\sum_{rs} \sum_k f_{rs}^{i^*} \delta_{a,k}^{rs} = v_a^i \quad \forall a \in A, i \in I
\end{align*}
\]

Here, \( x_{rs}^i \) is defined as
\[ x_{rs}^i = \sum_k r_{k,rs}^i \quad \forall r \in R, s \in S, i \in I \]

\( i \) denotes the network scenario.

The convex combination algorithm is used to solve the model, like the method Chi mentioned in 2010, this algorithm also utilizes the column generation to relax computational difficulty. In comparison with fixed matrix estimations, elastic matrix estimation is more realistic and can reflect the variability of subnetwork better.

Two example network change scenarios were used:

Scenario SF-1: Increasing the arc capacity of segment 11-10-16 from 0% to 300%;
Scenario SF-1: Increasing the arc capacity of segment 14-15-19 from 0% to 300%;

Here, a research example made by Chi was given to show the differences between some estimators. He used the Sioux falls network to verify it.
Differences between different estimators could be seen in figure 2. We can figure that an elastic origin-destination trip matrix estimator can produces OD flows more accurately and in turn arc flows than the fixed demand estimator. In this case, if we know all possible changes of the network, i.e., all the scenarios, and then we can get the elastic matrix. While Stephen D. Boyles (2011) pointed out a drawback of the elastic demand estimator ---- separable demand functions do not capture the full effect. The estimator posed by Chi assumed that the flow between each OD pair only depends on the OD travel cost. When traffic calming measures are taken in some roads, traffic flows and routes within the subnetwork may change, but the effect could not be captured if one is only modelling the subnetwork with separable demand function.
3.2. Dynamic origin-destination trip demand estimation for subnetwork

The models we list above are all static estimation methods which its decision variables do not change with the time changes. In reality, time-dependent network flows can better reflect the variable nature of a subnetwork trip matrix. At present, few researchers have taken into account dynamic method for subnetwork estimation, an exclusive case is due to Xuesong Zhou(2006) , who suggested a two-stage subnetwork demand estimation
procedure to provide an up-to-date time-dependent OD demand matrix for the subnetwork. The first stage aims to calculate the induced OD demand from the complete network which include the demand originating and/or terminating in the subnetwork and vehicular flows passing through the subnetwork. The second stage incorporates an iterative bi-level subarea OD updating procedure archived traffic measurements in the subnetwork. In this method, Zhou focused on E-E OD pairs.

The first stage utilizes an excess-demand traffic assignment formulation to capture the existing split of OD flows and considers a simple flow split function to deliver that estimate the most likely route flow pattern, and then a dynamic traffic assignment procedure is adopted. The second stage used a bi-level dynamic OD estimation formulation which includes a constrained ordinary least-squares problem and a elastic demand dynamic traffic assignment problem. A research example outcome is adopted in his article to show that a shorter time unit can better reflect the variable nature of a subnetwork trip matrix.

4. Conclusion and research extension

This study compares some estimation methods for subnetwork trip matrix from static and dynamic state respectively. Different models and algorithms are elaborated and their application conditions stated. Static methods are all utilizing the maximum entropy principle to get the OD matrix, which including fix and elastic origin-destination estimation. Dynamic method for subnetwork were only expounded by Zhou which could provide an up-to-date time-dependent matrix for subnetwork.

The induced trip matrix in research can be obtained via subnetwork trip matrix estimation which could serve as a basis for economic and environmental evaluation and local traffic impact assessment. Just as the trip modes of subnetwork mentioned above includes internal-external trips, external-internal trips and external-external trips, any of them could decides the variable nature of subnetwork OD flows. When some characteristics in the subnetwork have changed such as increasing the road capacity, building a new road and implementing traffic calming, any of them might have an effect on traffic flows inside the subnetwork and even the traffic diversion and route choosing of people outside the subnetwork. Due to we takes the subnetwork as the research center, all effects about subnetwork could be regarded as the change of flows through the boundary nodes of subnetwork. Thus the essential key to estimate the subnetwork OD demand is whether take the change mentioned above into account or not, that is whether the flows through the boundary nodes is get by equilibrium and flow conservative conditions.

Dynamic methods indeed can satisfy the requirement, but due to its complexity algorithm and the multitudinous archived counts, this method can not estimate the subnetwork trip matrix rapidly, especially when the subnetwork has many OD pairs. The author puts forward a kind of thought based on the research of Zhou(2006). Firstly, simplifying the topology outsides the subnetwork and creating the cost function of artificial arcs. Secondly, constructing a combined model of traffic assignment and traffic distribution. This method can guarantee that change of flows through the boundary nodes of subnetwork could be captured well when some characteristics of subnetwork have changed. The specific algorithm and example verification is still in the process of research.

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