A Method to Estimate Pedestrians’ Distribution in Underground Space Based on Entropy Maximization Approach and Pedestrian Flow Survey Data

Zongchao GU and Toshihiro OSARAGI

Abstract: Estimating passengers’ movements and spatio-temporal distribution is very important issue for passenger flow control and evacuation planning in underground spaces. Based on a pedestrian traffic survey in Fukuoka Tenjin Underground Shopping Area, this paper firstly proposes a network simplification to obtain determined constraints. Subject to these constraints an entropy model is developed to estimate the travel distribution matrix in underground shopping street. Using the proposed model it is possible to estimate the missing flow data in the network and clarify pedestrians’ spatio-temporal distribution in underground space.

Keywords: 地下空間 (underground space), 歩行者交通調査 (pedestrian traffic survey), エントロピー最大化法 (entropy maximization approach), 時空間分布 (spatio-temporal distribution)

1. Introduction

Transferring metro station gathers a large amount of passengers in station area. Estimating passengers’ movements and spatio-temporal distribution is very important issue for passenger flow control and evacuation planning in underground spaces.

The origin-destination (O-D) matrix is essential data for modelling passengers’ movement behaviour. However, it is generally difficult and costly to obtain O-D information by direct measurement, interviews or surveys. Based on information minimization and entropy maximization principles two models have been developed by Van Zuylen and Willumsen (1980) to estimate O-D matrix from traffic counts. Considering an uncongested network case, Cascetta and Nguyen (1988) presented a review of some alternative methods including maximum likelihood, generalized least squares, and the Bayesian approaches. Assuming passengers’ route-choice proportion independent from traffic volume, Dail (1970) has described a stochastic assignment model in the multipath assignment problem.

In this paper using pedestrian flow survey an entropy model is developed to represent the trip demand between entrances/exits. Through the network simplification approach it is available to obtain determined traffic flow constraints independent from multipath assignment at the beginning. By solving the entropy maximizing problem subject to
traffic flow constraints, we can estimate OD matrix and clarify pedestrians’ spatio-temporal distribution in underground space.

2. Data description

We use a pedestrian traffic survey in Tenjin Underground shopping Area (Fig.1) carried out by Fukuoka city government. The data contains passengers flow counts by each hour (7:00-21:00) in 7\(^{th}\) (Wednesday) and 11\(^{th}\) (Sunday) March, 2012. Fig. 2(a) shows the network system of underground shopping area. Circles mean the entrances/exits where pedestrians enter and departure this area and the red links have the flow counts in two directions, while no data were observed on black links. From the network we can know all the number of trips generated and attracted at each exit can be obtained by the flow counts on its connected link. However there are following two problems:

1) Not all links have flow counts data. (black links in Fig. 2(a))
2) Individual origin and destination are not obtained.

So pedestrians’ spatio-temporal distribution cannot directly be obtained from the survey data. Given this limitation, following approach is proposed to solve above problems.

3. Estimation method

3.1 Network simplification

As shown in Fig. 2(a), there are two avenues in the underground shopping area. One trip may have several possible routes that contain different links. The proportion of each path in passengers’ path choice is not clear at the beginning. To solve this problem we can adopt the multi-logit model if each path utility for passenger is known. The link parameters, such as distance, commercial attraction and facility services, are considered as influential factors for passengers’ path choice. It is difficult to make constraints according to the observed data in a complex network at beginning, because these parameters’ weights in utility function are not determined. To solve this problem, we combine two links at the same section in shopping area to one link-couple, and denote its flow counts by the total counts of two links. Then we get a simplified link network in Fig. 2(b). The simplified network system contains 47 observed links and 14 links without data.

3.2 Constraints of link-couple flow counts

Using the simplified network in Fig. 2(b), we can set constrains to the trips through each link-couple with

Fig. 1 Map of Tenjin Underground Shopping Area

Fig. 2 Pedestrian network based on underground map
observation data by following equation:

\[ V_s = \sum_{i=1}^{n} \sum_{j=1}^{n} T_{ij} M_{ij}^s, \]  

(1)

where

\[ M_{ij}^s = \begin{cases} 0, & \text{trip i to j not take s}, \\ 1, & \text{trip i to j takes s} \end{cases} \]

\( s \) stands for one observed link-couple in one direction.

\( V_s \) is the flow counts in the link-couple \( s \).

\( T_{ij} \) means the trip flow generated from entrance \( i \) to destination exit \( j \).

\( M_{ij}^s \) represents the possibility of link-couple \( s \) is used in the trip from \( i \) to \( j \).

3.3 Entropy model

Subject to the constraints of Eq. (1) and trip generation and attraction constraints at entrances/ exits, an entropy model is constructed to find a set of O-D flows with the maximum likelihood:

\[ \max - \left( \sum_{i=1}^{n} \sum_{j=1}^{n} T_{ij} \ln T_{ij} - T_{ij} \right) \]  

(2)

subject to

\[ O_i - \sum_{j=1}^{n} T_{ij} = 0 \quad \forall i \]  

(3)

\[ D_j - \sum_{i=1}^{n} T_{ij} = 0 \quad \forall j \]  

(4)

\[ V_s - \sum_{i=1}^{n} \sum_{j=1}^{n} T_{ij} M_{ij}^s = 0 \quad \forall s \]  

(1)

where \( O_i \) is the total number of trips originated at entrance \( i \), and \( D_j \) is the total number of trips destined for exit \( j \), and \( n \) is the total number of entrances/exits.

3.4 Parameter calibration

The problem is a nonlinear optimization program with linear equality constraints. For example, SQP (Sequential Quadratic Programming) algorithm (Nocedal and Wright, 2006) is a possible means to solve this kind of problem.

Fig. 3 shows the difference between total trips generation and destination during each time interval. The observation data is manually collected, so some errors are included in observed data. Besides that the counted trips cannot completely drop in the observation interval even though the observation interval (1 hour) is obviously longer than the trip time. Hence the non-correspondence between observation data and actual OD matrix may cause no feasible solution for the problem; Eq. (2). To address this situation we include the error variable \( \varepsilon \) to each constraint equation and change the equality constraints to inequality constraints as following.

\[ |O_i - \sum_{j=1}^{n} T_{ij}| \leq \varepsilon_{oi} \quad \forall i \]  

(5)

\[ |D_j - \sum_{i=1}^{n} T_{ij}| \leq \varepsilon_{dj} \quad \forall j \]  

(6)

\[ |V_s - \sum_{i=1}^{n} \sum_{j=1}^{n} T_{ij} M_{ij}^s| \leq \varepsilon_{vs} \quad \forall s \]  

(7)

Firstly denote \( \varepsilon \) in each constraint with a large value to achieve a possible solution. Then gradually decrease the error range on each constraint of link flow counts till the feasible solution is obtained.

4. A case study

To study passengers’ traffic demand at different time interval we select one-hour data at morning (8:00-9:00), noon (12:00-13:00) and evening (19:00-20:00) in a weekday as example, and estimate the OD matrices by described approach.

Fig. 4 has shown the fitness of estimated flow
counts. The error range can be decreased to 3.52% ~ 8.59% of the largest flow counts in the network. Fig. 5 has shown the trip distribution in estimated Origin-Destination matrixes. Different distribution tendency has been found at different time interval. At rush hour in the morning, trips mainly generate at three station-entrances and destined to the end of the underground street (zone 1 and zone 3) and other station-entrances. From 12:00 to 13:00 there are a large amount of trips between neighbouring office/commercial buildings. In the interval 19:00-20:00 the trips mainly generate from shopping malls and attracted to stations.

5. Conclusion

Based on a survey data, this paper proposes an entropy maximization method to estimate the OD matrix in target area. Trip distribution tendencies in three time intervals have been discussed by a case study. Trips assignment model in a complex network will be studied in the future.

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Reference:


Fig. 5 Trip distribution in estimated origin-destination matrix