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ORIGINAL ARTICLE

Calibrating a trip distribution gravity model stratified by the trip purposes for the city of Alexandria

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Abstract The trip distribution is the most important yet the most misunderstood model in the Urban Transportation Planning Process (UTPP). One overlooked aspect is the different sensitivities in choosing the destinations based on the trip purposes. This paper proposes a framework to calibrate a doubly-constrained gravity model for the trip distribution of the city of Alexandria based on a Household Travel Survey carried out in 2002. The trip ends are estimated from the available census data. Important parameters for the trip attraction models were estimated and validated in the course of this research. Since a small sample is used, a simple, effective weighing technique is applied to mitigate the sample bias. The purpose-based dispersion parameters are estimated based on the weighted sample. The model validation is also introduced in terms of trip length distribution, intrazonal trips and the distribution of the trip interchanges between city parts. The proposed model demonstrates the different patterns of trip distribution per purpose. It also shows a considerable shift toward non-compulsory trip purposes in the city of Alexandria.

1. Introduction

Urban Transportation Planning Process (UTPP) is a multi-stage process which includes transportation models such as trip generation, trip distribution, mode choice and trip assignment. A model is defined as a simplified representation of part of the real world which concentrates on certain elements considered important for the analysis from a particular point of view.Trip generation is a stage of a classical transportation models that aims at predicting the total number of trips generated by (O_i) and attracted to (D_j) each zone of the study area (i.e., originated from and destined to each zone). This total number of trips generated by households in a zone depends on the personal trip productions (e.g., car ownership, income, household structure and family size) and personal trip attractions (e.g., number of employees and total areas of businesses).

Trip distribution model is the second stage of transportation models. This step matches trip maker origins and destinations estimated by trip generation models to develop a 'Trip

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Tables'. A trip table is a matrix that displays the number of trips going from each origin to each destination.

The most well known models of trip distribution are gravity model, Logit model and Entropy Maximization model. Trip distribution model depends on travel distance (time) between each pair of zones.

Trip distribution models of a different kind have been developed to assist in forecasting future trip patterns when important changes in network take place. Over the year, modelers have used several different formulations of trip distribution. The first was Frater or growth model. This structure extrapolated a base year trip table to the future based on a growth factor(s), but took no account of changing spatial accessibility due to increased supply or changes in travel patterns and congestion. The next well known model developed was the gravity model, which was originally generated from an analog with Newton gravitation law. The first use of the gravity occurred in 1950s.

With the development of logit and other discrete choice techniques as a derivative of the random utility model, new, demographically disaggregate approaches to travel demand modeling were attempted. By including variables other than travel time in determining the probability of making a trip, it is expected to have a better prediction of travel behavior. The logit model and the singly-constrained gravity model have been shown by Wilson [15] to be of essentially the same form. The application of these models differs in concept in that the gravity model uses impedance of travel time, perhaps stratified by socioeconomic variables, in determining the probability of trip making, while a discrete choice approach brings those variables inside the utility or impedance function. For example, the logit model expresses the destination choice as a function of the utility of choosing one alternative over another. In general, discrete choice models require more information to estimate and more computational time.

The notion of entropy maximization offers a theoretical framework for spatial interaction models. The concept of entropy maximizing or minimum dispersion arose from the observations that urban travel choices do not reflect the cost minimizing behavior. Based on statistical mechanics, entropy is concerned with finding the degree of likelihood of the final state of a system. Data for urban systems are not usually abundantly available. Therefore, a method is needed for making reasoned estimates of the likely state of an urban system using the available information. In this sense, the entropy is maximized subject to constraints of known information. The entropy maximization approach used in generating a wide range of models including the gravity model. In fact, the entropy-type constraint has been shown by Erlander [6] to be equivalent to a singly constrained gravity model and by Fisk [9] to be equivalent to logit choice function.

The purpose of this research is to develop and calibrate a doubly-constrained trip distribution model for the city of Alexandria, Egypt. A small sample of data has been collected for the city of Alexandria. The proposed model is a framework of modeling trip distribution for the purpose of analyzing the travel behavior of trip makers for different purposes. A simple, optimizing and effective weighing technique is applied to mitigate the sample bias associated with small sample used in this paper. The dispersion parameters are estimated based on the weighted sample for each purpose. The model validation is also introduced in terms of – among other measures – the trip length distribution relative to the city size and the trip purpose.

In order to calibrate trip distribution, an estimated trip generation for each zone needed to be obtained. The average trip rate for the entire city of 1.2 trips/inhabitant/day was estimated as a part of 1982 TranSyatem study [14]. A research by the author in 2004 [1] indicated that this trip rate should be increased by at least 10% to an updated rate of 1.32 trips/inhabitant/day. The estimates of trips produced from and attracted to each zone were essentially based on the latest average trip rate.

2. Model structure

2.1. Model formulation

The gravity model is much like Newton's theory of gravity. The gravity model assumes that the trips produced at an origin and attracted to a destination are directly proportional to the total trip productions at the origin and the total trip attractions at the destinations and inversely proportional to the distance (separation) between the origin and destination. The separation between the origin and destination zones is better be formulated as a decreasing function which is known as deterrence function. For a study area divided into Z zones, the model can be represented in the following functional form [12]:

$$T_{ij} = \alpha O_i D_j f(c_{ij}) \qquad \forall i,j \in Z \qquad (1)$$

where T_{ij} is the trips produced in an origin zone i and destination zone j, O_i, D_j the total trip ends produced at i and attracted at j, $f(c_{ij})$ the generalized function of travel costs between any pair of zones i and j, α is the a proportionality factor.One version of this travel cost (deterrence) function that will be used throughout this paper is given as follows:

$$f(c_{ij}) = e^{(-\beta d_{ij})} \qquad \forall i,j \in Z \qquad (2)$$

where β is the dispersion parameter, d_{ij} the distance between zones i and j.The sum of the trips produced between any origin zone i and all destination zones $j \in Z$ should be equal to the total trip ends produced at the origin zone. Similar statement can be made for any destination zone. These are known as the flow conservation constraints and are given as follows:

$$\sum_j T_{ij} = O_i \qquad \forall i \in Z \qquad (3)$$

$$\sum_i T_{ij} = D_j \qquad \forall j \in Z \qquad (4)$$

To ensure the flow conservation constraints given in Eqs. (3) and (4), the single proportionality factor α should be replaced by two sets of balancing factors A_i and B_j. Introducing these balancing factors in Eq. (1) results in the classical version of the doubly constrained gravity model which is given as follows [12]:

$$T_{ij} = A_i O_i B_j D_j f(c_{ij}) \qquad \forall i,j \in Z \qquad (5)$$

where

$$A_i = \frac{1}{\sum_j B_j D_j f(c_{ij})} \qquad \forall i \in Z \qquad (6)$$