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DEVELOPMENT OF COMBINED TRIP GENERATION, TRIP DISTRIBUTION, MODE CHOICE AND ROUTE CHOICE AS SIMULTANEOUS MODEL RESEARCH REVIEW

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Abstract: The development of combined trip generation, trip distribution, mode choice and route choice to obtain the O-D matrices is well advanced. Therefore, positive results on this development will be further developed by combining each part of four step models. The previous research represents combination from sub-models series in which each series must be done separately and successively as well. With this combination model, modeling process become shorter and faster thus the result is comply with each phase of expectation. Besides, consistency between the model phases which were combined can be more guaranteed, due to the definition and input were utilized the same materials in the models.

Key Words*: Simultaneous Model, Four Step Model, efficiency and effective.*

1. INTRODUCTION

There are a few concepts of transportation planning which have developed recently, thus the most popular one is The Four Step of Transportation Planning Model. This model represents combination from sub-models series in which each series must be done separately and successively as well.

The four step model is very complex, required a lot of data and times in developing process and calibration. This time a lot of combination model have been developed, then the parameter is calibrated by traffic flow. The combination represent one step of model development which is efficiency and effective.

With this combination model, modeling process become shorter and faster thus the result is comply with each phase of expectation. Besides, consistency between the model phases which were combined can be more guaranteed, due to the definition and input were utilized the same materials in the models.

2. COMBINED TRIP GENERATION-TRIP DISTRIBUTION

A general approach to the explanation of transport flows that combines into a consistent format the traditional mode choice and generation-distribution models and enriches the overall explanatory power of these models was developed. The specification of the Generation- Distribution model required three more variables, all of which were constructed.

The resulting specification is relatively simple, but adequate to demonstrate the usefulness of our chosen approach. More refined specifications that would incorporate, for instance, descriptors of the job mix (manufacturing, services, etc.) would be of certain interest but unlikely to modify deeply our results. The same may or may not be true of dummy variables to account for border effects: duly taking spatial correlation into account is probably insufficient to control for the fact that some cities are next to a border (the sea, the DDR, France, etc.) which conditions trip making either because it is not included in the model (trips abroad are excluded) or because reduced travel opportunities may increase flows to available opportunities: the number of contiguous neighbour affects the matrix because, by the normalization procedure, lines where there are relatively many non-zero elements will give smaller weight to these observations than those containing fewer non-zero elements. However, this may not suffice to remove border effects. Only a more detailed study could, by adding border area dummy variables, answer the question.

A. In terms of specification, the chosen quasi-direct format

A.1. uses in the generation-distribution formula a meaningful index of the attractiveness or utility of the available transportation alternatives. Frequently, generation-distribution models use a very simplistic specification of the importance of transportation, typically representing its role by a single variable, such as cost or distance by a prevailing mode. In our approach, all price and service levels of all available modes appear in the index because it is defined as the denominator of the logit mode choice model itself. In consequence, a particular transport price or service influences both modal choice and the total amount of trip making. Moreover, it is known from utility theory that, under certain conditions, the natural logarithm of the index has a strict interpretation as the expected maximum utility available over all transportation modes.

A.2. adds to the pair-specific variables currently used to explain each specific origin-destination flow the influence of other alternatives. The most questionable feature of the specification of generation-distribution models is that they make the flow for a given origin-destination pair depend only upon the transport and socioeconomic conditions of that pair because collinear arises as soon as the determinants of other opportunities are also used – assuming that one can even select the appropriate subset of relevant other competing or complementary opportunities. Our approach solves both the selection and the collinear problems by formulating testable hypotheses for the selection of relevant alternatives on the basis of correlation among error terms (normally caused by missing explanatory variables in the models) and weighing the importance of such additional alternatives through a correlation parameter that should generally reduce multi collinear. This indirect way of introducing "other" variables than "own" variables in the explanation of flows is flexible and adaptable to the specifics of each problem.

B. In terms of calibration of the importance of all variables, our procedures allow the data to determine whether the best mathematical form is that most frequently used or different, for instance

B.1. in the mode choice model we test whether changes at the margin have a constant influence on choice probabilities, and the extent to which, in particular, asymmetric reaction thresholds may be present.
We naturally use as mode choice model the logit model but probe the mathematical form of the utility functions. We reject the linear form. Although generally used, this form incorporates the implicit assumption that modifications in travel conditions have effects that

are independent of trip length and uniform across the modes. The values of the estimated Box-Cox transformations indicate that utility functions are nonlinear and imply the existence of asymmetric thresholds in the reaction of traveler. Our flexible specification therefore strongly rejects the popular linear form often accepted without due probing of its behavioral meaning and empirical validity.

B.2. in the generation-distribution piece proper, we allow the interaction to be calibrated and the data to move away from the common multiplicative form. Although it is natural to expect spatial interactions, such as transport or communication flows, to be determined by a structure in which the influence of each variable depends on the level of that variable and other variables, as happens in a multiplicative model, we fine tune the nature of this interaction, again through the use of Box-Cox transformations. We find that some of the variables should enter multiplicatively, but that others should not and may even enter additively. We find large gains in adjustment to the data even when numerical values obtained for the transformations are not apparently very different form those corresponding to a multiplicative form.

C. In terms of extraction of information from the data, we purge the residual errors from systematic information that they may contain, thus simultaneously obtaining conditions of the randomness, constancy of variance and independence that make our statistical tests more reliable. Due to the fact that it is impossible to specify a perfect model, it is essential to make a model of the error terms, to extract systematic information that they are expected to contain. The formulation of systematic relationships to account for correlations among observations, or correct the error variance in order to make it constant, is essential not only to account for observed flows as adequately as possible, but also to obtain a model error that satisfies conditions under which unbiased statistics – such as t-statistics – can be obtained. Such models of error terms also influence the estimates obtained for all parameters of the structure. They influence the meaning of the structure, modify the effective patterns of correlation among explanatory variables and qualify the measures of certainty and various tests that are usually performed for any explanatory structure. Our particular emphasis on the spatial nature of information contained in transportation models in particular requires major innovations in existing calibration procedures. We found that such probing had significant impacts on the model parameters, notably on the elasticity of demand, and that the impacts were in the expected direction: it has been shown elsewhere (Picard, Nguyen and Gaudry, 1988) that impedances produced by these models are too high because they do not take into account the input-output constraints that hold for the economy as whole and incorporate a specific competitive spatial structure. Our approach is therefore rich in terms of specification, flexible in terms of functional form and effective in terms of extraction of information, or adjustment to the data.

3. COMBINED TRIP DISTRIBUTION AND MODE CHOICE

The estimation of public transport demand, particularly important for planning purposes especially in developing countries, is an expensive and time consuming undertaking. The need of low-cost method to estimate the public transport demand is therefore obvious. The development of techniques for calibrating the trip distribution models from traffic counts to obtain the O-D matrices is well advanced (see **Tamin, 1988**; **Tamin and Willumsen, 1988**; **Tamin, 1992**).

The paper discusses the development of ② methods and techniques for modelling the public transport demand using low-cost and easily-available traffic (passenger) count information and other simple zonal-planning data. The paper will report on a family of aggregate model combined with a family of mode choice logit model which can be calibrated from traffic (passenger) counts and other low-cost data. The model examined was the **Gravity (GR)** model combined with the **Multinomial Logit (MNL)** model. **Non-Linear-Least- Squares (NLLS)** and **Maximum-Likelihood** estimation methods were used to calibrate the parameter of the combined model. The combined **TDMC** model and the calibration method have been implemented into a micro-computer package capable of dealing with the study area consisting of up to 300 zones, 3000 links and 6000 nodes. The approach has been tested using the 1999 Public Transport Data Survey in Bandung (Indonesia). The model was able to obtain the calibrated parameters which can then be used for forecasting purposes. However, the results were not so encouraging due to the poor public transport data and poor O-D public and private transport matrices. General conclusion regarding the advantageous and the applicability of the approach to other environments are given at the end of the paper.

Therefore, positive results on this development will be further developed and extended to enable the transport planner to estimate the demand for public transport for short, medium or long term planning. The main idea is by combining a **Trip Distribution and Mode Choice** (**TDMC**) model and calibrating it using low-cost traffic (passenger) count information (see **Ortuzar, 1989**). One can interpret link flows (or traffic counts) as resulting from a combination of two elements: **an O-D matrix** and **the route choice** pattern selected by drivers on the network. Under normal circumstances there will never be enough traffic counts to identify a single O-D matrix as the only possible source of the observed flows. Traffic counts alone are not enough to estimate O-D matrices, something else is needed.

The idea of combining '**traditional**' data sources (home or roadside interviews) with low cost data like traffic counts is not entirely new (see **Van Zuylen and Willumsen, 1980** and **Tamin 1988, 1990**). The models can be used to combine, for example, roadside interview data with traffic (passenger) counts and this can be achieved with or without an explicit travel demand model (trip distribution model). For the purpose of public transport demand estimation, this idea can be extended to the development of a practical estimation approach to calibrate the combined **Trip Distribution and Mode Choice (TDMC)** model with traffic (passenger) counts and other simple zonal planning data.

This approach assumes that either trip distribution or mode choice model is represented by certain model forms. As usual, the traffic (passenger) counts are expressed as a function of the TDMC model. In this case, the TDMC model is represented by a function of a model form and relevant parameters. The parameters of the postulated model are then estimated, so that the errors between the estimated and observed traffic (passenger) counts are minimized.

Fundamental basis

$$\mathbf{T}_{id}^{k} = \mathbf{T}_{id} \cdot \frac{\exp\left(-\beta.\mathbf{C}_{id}^{k}\right)}{\sum_{m} \exp\left(-\beta.\mathbf{C}_{id}^{m}\right)} \qquad (1)$$

Then '**the fundamental equation**' for the estimation of a combined transport demand model from traffic counts is:

$$\mathbf{V}_l^k = \sum_d \sum_i \left[\mathbf{O}_i^k . \mathbf{D}_d^k . \mathbf{A}_i^k . \mathbf{B}_d^k . \mathbf{f}_{id}^k . \mathbf{p}_{id}^{lk} \frac{\exp\left(-\beta . \mathbf{C}_{id}^k\right)}{\sum_m \exp\left(-\beta . \mathbf{C}_{id}^m\right)} \right] \qquad (2)$$

The main idea of this method is to estimate the unknown parameter which minimizes the sum of the squared differences between the estimated and observed traffic counts. The problem now is:

to minimize $$\mathbf{S} = \sum_l \left[\mathbf{V}_l^{+k} - \mathbf{V}_l^k \right]^2 \qquad (3)$$

$$\frac{\delta S}{\delta \beta} = \sum_l \left[\left(2 \sum_i \sum_d \mathbf{T}_{id}^k . \mathbf{p}_{id}^{lk} - \mathbf{V}_l^k \right) \left(\frac{\sum_i \sum_d \delta \mathbf{T}_{id}^k}{\delta \beta . \mathbf{p}_{id}^{lk}} \right) \right] = 0 \qquad (4)$$

Equation (4) is a equation which has one unknown parameter ***β*** need to be estimated. Then it is possible to determine uniquely all the parameters, provided that **L≥1**. **Newton**'s method is then be used to solve equation (4).

The resulting equation was then solved by **Newton**'s method and **Gauss-Jordan Matrix Elimination**. All programs were written to be fully integrated and interactive with the **MOTORS** transport planning suite. Some conclusions can be drawn from the result obtained:

- The number of observed traffic (passenger) counts required are at least as many as the number of parameters. The more link flows you have, the faster the estimation method will converge and also the more accurate the estimated O-D matrix we have.
- The calibrated model can then be used to forecast and also to evaluate the effect of ticket fare to the public transport demand.
- It is found that by having the information of traffic (passenger) flows using Angkot, we can obtain the O-D matrices for private and Angkot.
- However, the results were not so encouraging due to the poor public transport data and poor O-D public and private transport matrices.

4. COMBINED TRIP DISTRIBUTION, MODAL SPLIT AND ROUTE CHOICE

Fernandes present a modeling approach for solving quite general network equilibrium problems (with fixed trip productions and attractions) intrinsic to the urban transportation planning process. The model developed is able to consider a variety of demand models and route choice behaviors within the same implementation including multiple user classes and combined travel modes that interact on the same physical network. The demand choices are assumed to have a hierarchical structure. When trip distribution is variable, a doubly constrained entropy-maximizing model is considered at the first level of choice and a hierarchical logit model is used for the remaining demand choices (time of departure, travel mode, transfer point for combined modes, etc.). If trip distribution is considered to be exogenous, the demand choices are modeled as a hierarchical logit. One of the model's main features is that it considers the effects of congestion on the road network as well as congestion and capacity constraints effects in each public transport service network. The problem is mathematically formulated as a variational inequality, with asymmetric cost functions, and is solved following the diagonalization procedure. Each iteration of the aforementioned procedure solves an optimization problem using the Evans algorithm.

Sufficient conditions for the existence and uniqueness of the solution to the diagonalized problem are obtained. The main results of a simple example (solved with an academic version of the proposed algorithm) are presented to show the consistency of the equilibrium flows and levels of services obtained using the model. Finally, we briefly describe a real scale implementation of the model, in order to show the feasibility of its application.

An important number of large size metropolitan areas have experienced increasing levels of vehicle congestion, which in many cases has contributed to serious pollution problems. Because of this, government authorities must often face demands from the population and various interest groups to improve operating conditions of urban transportation systems and to build very expensive infrastructure projects (new metro lines, urban highways, etc.). Nevertheless, these options are normally very expensive, especially for developing countries with very limited capital resources that have many alternative uses in various social areas such as education, health, housing and others.

In order to make rational decisions with respect to the future development of their main urban transportation systems, many national, regional and local government authorities all over the world have implemented planning methods that often include computer models, to simulate the operation of alternative network configurations and evaluate strategic plans. An important number of these methodologies are based on the use of the traditional sequential four step procedure, whose lack of consistency among the levels of service and flow values obtained at each stage is a very important shortcoming when congestion exists (see Boyce, 2002, and Boyce,1994).

As an alternative way of modeling supply-demand equilibrium in transportation systems, many combined (simultaneous*) equilibrium models have been formulated. Although important progress on this issue has been observed during the last decades, it is quite surprising that very few large-scale applications have been reported (a comparison of different simultaneous equilibrium models is presented in Boyce and Bar Gera, 2004). One of the most critical aspects explaining this important gap between the research and the state of the practice seems to be the late development of adequate transit assignment algorithms (see De Cea and Fernández, 2000). While road equilibrium assignment models were available more than 30 years ago, the equivalent models to analyze real size transit networks are not older than 12 years. It is quite clear that in the context of combined equilibrium models the fact of not considering congestion associated with transit modes constitutes an important modeling limitation, specially when that models are used to predict equilibriums for future years. Thus, as a consequence of the very limited use of combined models in practice, many implementation problems are not well understood and the importance of some modeling limitations present in the majority of these existing formulations have not been evaluated properly with experimental results.

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The main objective of this paper is to describe a general modeling framework to formulate, in a flexible way, a variety of multi class and multimodal network equilibrium problems, usually present in transportation planning. Considering trip productions and attractions exogenously defined, the model 1 is formulated as a variational inequality with **asymmetric flow dependent cost functions**, and the particular problems are all solved using the diagonalization algorithm.

Florian (1977) developed a two mode (private car and transit) network equilibrium model where the most important features are the distinction between the flow of vehicles and flow of transit passengers and the means of modeling the interaction between both types of vehicles that use the same road links of the network. In this case, non-separable demand functions are used to more realistically capture demand-side interdependence. The equilibrium is found by solving a sequence of problems like the one proposed by Beckmann et al. for one mode (car), while parametrically varying the equilibrium travel costs of the other mode (transit) whose assignment is determined by an all-or-nothing technique.

Aashtiani (1979) was the first author who proposed an optimization model for the performance-demand equilibrium problem with non-separable cost and demand functions to capture the interdependence (interactions) between different modes (user classes). When these interactions are assumed to be symmetric, an optimization problem whose objective function can be expressed in terms of line integrals exists (this is an extension of the work developed by Dafermos (1971,1972), for the traffic equilibrium problem with multiple user classes, with asymmetric interactions).

The lack of realism of the optimization problems formulated in order to model multimodal and multiclass equilibrium on transportation systems with symmetric interactions between users of different modes or classes, gave place to a number of alternative and more realistic formulations. In fact, the work reported by Florian (1977) has been considered a particular form of a variational inequality formulation for performance-demand network equilibrium models with asymmetric link cost functions.

Concerning the D-MS-A problem, the following figure illustrates one branch of the decision tree (demand choices) for a given origin-destination pair *w*, of a class *k* user, and with trip purpose *p*. The tree's highest level has as many branches, equivalent to the ones represented in the figure, as origin-destination pairs *w*, user classes *k* and trip purposes *p*, exist. The destination choices for each user class and trip purpose are represented in the uppermost level (not shown in the figure), while in the lowest level (actually in the two lowest levels), mode choices are represented in a hierachical logit structure (Williams, 1977).

The corresponding utility (disutility) function is shown in each tree level. In the lowest level, each mode *m* has its associated disutility (a linear function representing the generalized travel cost between pair *w*, for users of class *k*, with trip purpose *p*, using transportation mode *m*). For instance, in the case of car driver mode this cost considers travel time, operating costs, fares (when road pricing schemes are considered), etc. For the public transport modes, the specification of the disutility functions includes terms like access time, waiting time, in-vehicle travel time, fares and transfer penalties.

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5. COMBINED TRIP GENERATION, MODE CHOICE AND ROUTE CHOICE

Two multi class models of origin-destination (O–D), mode, and route choice were formulated, estimated, and validated. The first model corresponds to a simultaneous O-D and mode choice model with a single exponential function of generalized travel cost. The second separates O-D choice and mode choice into separate, but interrelated, exponential functions, and may be described as a nested logit model. Both model formulations are constrained with regard to origins and destinations by class. This terminology was suggested by Abrahamsson and Lundqvist (1999). In this section, following a statement of the model assumptions, an equivalent optimization problem is formulated, and its optimality conditions are related to standard choice models. Additional constraints are then added to convert this model into the nested logit formulation and its optimality conditions are presented.

Two modes, auto (au) and transit (tr), are considered to operate over independent networks, so that the generalized costs associated with each mode are separate. The costs of the transit mode are fixed and given by a timetable and fare schedule. The generalized travel costs are linear, weighted functions of in-vehicle and out-of-vehicle travel time and monetary costs, as well as over-the-route distance in the case of autos. The in-vehicle travel time on each link of the road network is an increasing function of the link's own total flow. Out-of vehicle times on the road network are fixed access and egress times associated with origins and destinations. Exogenous monetary costs on the road network represent link tolls and parking fees at destinations. The vehicle operating cost of a link is assumed to be an implicit linear function of link travel time (minutes) and link length (miles). No assumption is made concerning the relation of operating cost to link travel time or length, or to vehicle occupancy; instead, time and length are assumed to be variables in the generalized cost function that affect both the disutility of personal travel and the associated auto operating cost. The joint effects of these variables are represented by the estimated coefficients. Transit monetary cost is the transit fare. In making their origin-destination-mode choices, travelers are assumed to minimize the generalized cost of travel (disutility), subject to a dispersion of choices to higher cost alternatives, which seeks to account for variables and other factors not included in the model. This dispersion is represented by the entropy function, a measure of dispersion of a frequency distribution, and its associated cost sensitivity coefficient. Choice of route on the road network is assumed to be strictly cost-minimizing with perfect information concerning the generalized cost of the route. This assumption corresponds to the first principle of Wardrop (1952), generally known as user-optimal route choice.

The research findings summarized in this paper describe the formulation, estimation, and validation of a large-scale, multi class model of peak period urban travel. The findings demonstrate the feasibility of implementing and using a model that achieves the internal consistency between O-D-mode flows and auto travel times regarded as important to travel forecasting. In other words, all feedback relationships are rigorously represented in the formulation and implemented in the model solution. Moreover, the estimated coefficients are internally consistent with the model structure and the endogenous predicted travel times over the road network. Limitations of time and budget, as well as lack of perfect foresight, tended to reduce the quality of the results below what might have been accomplished otherwise. Nevertheless, the model was estimated and validated in a completely new way from the viewpoint of urban transportation research and practice. Even so, more detailed model testing and implementation studies remain to be accomplished before this model can be regarded as ready for use in practice. Alternative model functional forms should be investigated, especially the more general deterrence function that combines the negative exponential function with the power function. In adopting that function, it appears that the optimization framework used in this research must be discarded. However, recent research findings by Bar-Gera and Boyce (2003) illustrate the feasibility of solving such models directly in a fixed-point framework. Finally, for such a model formulation and estimation procedure to be applied in professional practice, improved software systems need to be devised. Although much progress has been made in the last decade in software systems for transportation planning, the requirements for this model go well beyond existing systems. Nevertheless, we are optimistic that ongoing improvements will be made available to the professional community in the future.

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