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An Integrated Urban Land Use and Transportation Demand Model Based on Lowry Linage

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Abstract: Here, we concentrate on the equilibrium modeling of Integrated Land Use and Transportation Demand Model (ILUTDM). We propose two combined sub models to involve in the ILUTDM: 1- residential activity location choices, trip distribution, mode choices and route choices, 2-employment location choices, trip distribution, mode choices and route choices. In the both combined sub models is assumed each individual minimize his or her travel cost and maximize his or her living or service utility. The joint choice of the residential or the employment location and transportation destination and mode of the two sub models is formulated as a nested multinomial logit model. We reformulate the combined sub models as an Equivalent Minimization Problem (EMP). The Evans algorithm may be applied to the EMP, in purpose of a realistic application within a reasonable time period. Finally, we develop an ILUTDM that contains the economic-base mechanism, the proposed combined sub models and the constraint procedure and their interactions.

Key words: Combined model, activity location choices, travel choices, equivalent minimization problem

INTRODUCTION

A model which reflects the interactions between several decisions or sub systems, like for example location patterns, trip flows, house prices and trip frequencies, are called integrated models or models for integrated analysis. One of the first models in land use modeling was developed by Lowry (1964) for the Pittsburgh urban region. He distinguished population, service employment and basic employment and these activities correspond to residential, service and industrial land uses. Activities are translated into appropriate land uses by means of land use/activity ratios. The division of employment into service and basic sectors reflects the use of the economic base method to generate service employment and population from basic employment. The Lowry model allocates these activities to the zones according to the potential of the zones. Population is allocated in proportion to the population potential of each zone and service employment in proportion to the employment potential of each zone, subject to capacity constraints on the amount of land use accommodated in each zone. Consistency is secured by feeding back into the model and reiterating the whole allocation procedure until the distribution inputs to the model are coincident with the outputs.

Garin (1966) suggested to replace the potential models by production-constrained gravity models and substituted another economic base mechanism for the analytic form. Another example is the Projective Land Use Model (PLUM) was designed by Goldner (1971). He replaced potentials by gravity models to allocate land uses.

Perhaps the most widely used model is Integrated Transportation and Land Use Package (ITLUP) (Putman, 1991). In the ITLUP, the land use model was a modification of Goldner's Version of the Garin-Lowry model of land use and the network model was a conventional capacity-constrained incremental assignment model (see Mackett (1991) and Wegener (1994) for more extensions on the Lowry model).

Integrated Land Use and Transportation Demand Model (ILUTDM) can be considered as extensions of the network User-Equilibrium (UE) equivalent mathematical problem (Zhao, 2002). These extensions can combine various types of land use models under a general network equilibrium framework to overcome shortcoming of the traditional four step approach include inconsistency among steps and the lack of behavioral theory behind the traditional model (Maruyaman and Harata, 2005). For example, Shen (1997) derived a network equilibrium framework to combine travel and residential location choices. His model combines the network equilibrium

models with the Disaggregate Residential Allocation Model (DRAM) and is formulated into convex programming problems. Chu (1999) presented a model based on a UE framework and a transformed EMPLOYMENT ALLOCATION (EMPAL) model to jointly determine employment location and travel choices. DRAM and EMPAL were proposed by Putman (1991).

Based on the analysis of solution approaches for the original Lowry model and its generalized versions, Pietrantonio (2001) suggested a framework for the equivalent optimization approach. Important conclusion of his work was “there is no fully Equivalent Minimization Problem (EMP) formulation for the Lowry model as originally formulated with using unique model”.

As a worth point, the Lowry lineage had its nascence as an outgrowth from conventional models used for transport planning since the sixties.

In this study, based on the previous discussion, we consider the mains selected features:

- The inclusion of network congestion, as the more basic step into the integration of land use and transport models that were dealt with heuristically into several models
- The inclusion of network equilibrium framework to combine travel and activity location choices simultaneously
- The inclusion of the well-known random utility maximization behavioral theory

Considering these features in a unique framework is motivation of developing a generalized version of the Lowry model in this study. To develop integrated transportation-land use framework, we propose two combined sub models in the following define:

- The Combined Residential activity location choices, trip Distribution, Mode choices and Route choices model (CRDMR)
- The Combined Service employment location choices, trip Distribution, Mode choices and Route choices model (CSDMR)

In the both combined sub models is assumed each individual minimize his or her travel cost and maximize his or her living or service utility.

We reformulate each above combined sub models into EMP form such as the equilibrium conditions on the network and travel demand functions can be derived as the Karush-Kuhn-Tucker (KKT) conditions. We extend Evans algorithm (Evans, 1973) and use it to solve the equilibrium problem.

Finally, we develop an ILUTDM based on Lowry lineage that contains the economic-base mechanism, the proposed combined sub models and the constraint procedure and their interactions.

MATERIALS AND METHODS

Activity location choice models (residential and employment): Spatial activity location models are concerned with representing people's location decisions in terms of where to live given the place of work, or where to work given the place of residence. These models can be based on the theory of entropy, or on the theory of random utility. Both lead to the same model specifications (Shen, 1997).

Hereto, the selected activity location choice models are simplified form of the DRAM and the EMPAL developed by Putman (1991). Putman models require relatively less data compare to others models and have been tested in many practical applications (Shen, 1997).

Residential location model: The general form of DRAM is given by:

$$H_{i,t} = u_{i,t-1} \cdot \sum_j E_{j,t}^b \frac{W_{i,t-1}^r f^r(c_{ij,t})}{\sum_l W_{l,t-1}^r f^r(c_{lj,t})} \quad \forall (i \in I, j \in J) \quad (1)$$

Where:

- $H_{i,t}$ = No. of residents (place-of-residence) in the zone i at time t
- $E_{j,t}^b$ = No. of employees working in the zone j at time t
- $u_{i,t-1}$ = Population/employee ratio in the zone i at time $t-1$
- $W_{i,t-1}^r$ = Residential location attractiveness measures in the zone i at time $t-1$
- $f^r(c_{i,j,t}^r)$ = Impedance functions for work to home trips at time t
- $c_{ij,t}$ = Travel cost from the zone i to the zone j at time t

The attractiveness measure function attempts to express both land use characteristics and the effect of household to household interaction on the location behaviors of different household types (Putman, 1991). The multivariate and multi-parameter function comes into the following form:

$$W_{i,t} = L_{v,i,t-1}^n \cdot X_{r,i,t-1}^n \cdot L_{r,i,t-1}^o \cdot \prod_n \left(1 + \frac{H_{i,t-1}^n}{\sum_n H_{i,t-1}^n} \right)^{p_n} \quad \forall i \in I \quad (2)$$

Where:

- $L_{i,t-1}^v$ = Vacant, buildable land in the zone i
- $X_{i,t-1}^p$ = Proportion of buildable land in the zone i that has already been build on
- $L_{i,t-1}^r$ = Residential land in the zone i
- $H_{i,t-1}^n$ = No. of type n residents residing in the zone i
- $H_{i,t-1}^{n'}$ = Employed residents of the zone i in income group n' at time t-1
- m, n, o, p = Estimated parameters for each group being located

Because each income group is analyzed independently in the model calibration process, the model can be expressed as a simple form without the income group, n, being shown in Eq. 2.

Service employment location model: The general form of this model is defined as follows:

$$E_{j,t}^s = \sum_i v_{i,t-1} H_{i,t} \frac{W_{i,t-1}^s f^s(c_{ij,t})}{\sum_i W_{i,t-1}^s f^s(c_{i,t})} \quad \forall j \in J \quad (3)$$

Where:

- $E_{j,t}^s$ = Service employment (place-of-work) in the zone j at time t
- $v_{i,t-1}$ = Service employee/population ratio

The attractiveness measure is given by:

$$W_{j,t-1}^s = (E_{j,t-1}^s)^{a^s} L_j^{b^s} \quad (4)$$

Where:

- L_j = Total area of the zone j
- a^s, b^s = Estimated parameters

We assume the zone to zone impedance function is a simple declining exponential function, therefore:

$$f^{r,s}(c_{ij}) = \exp(-\theta^{r,s} \cdot c_{ij}) \quad (5)$$

Where:

- $\theta^{r,s}$ = Empirically estimated parameters

The location models in Eq. 1 and 3 are essentially a standard singly constrained spatial interaction model augmented with a multivariate attractiveness term. The length of the interval between t-1 and t is determined on the basis of the hypothesis that the model is intended to interpret the lagged effect of developments of land use on transportation. In all previous applications the length of

the interval has been 5 years (Shen, 1997). For convenience of the following presentation, we drop the notation of time t.

Trip distribution and mode choice model: The main purpose of trip distribution modeling is to distribute the total number of trips originating in each zone among all possible destination zones which are available. The location models shown in Equations 1 and 3 are actually a trip-end summation of a zone-to-zone trip estimation procedure. The model used to distribute trips between zones is the well-known standard singly constrained gravity model as follow:

$$T_{ij}^{r,s} = O_{j,i}^{r,s} \frac{W_{i,j}^{r,s} \exp(-\theta^{r,s} \cdot c_{ij})}{\sum_1 W_1^{r,s} \exp(-\theta^{r,s} \cdot c_{ij,t})} \quad \forall (i \in I, j \in J) \quad (6)$$

Where:

$$O_j^r = \varphi^r \cdot E_j^b \quad \text{and} \quad O_i^s = \varphi^s \cdot v_i \cdot H_i \quad (7)$$

- $T_{ij}^{r,s}$ = No. of trips for home-work and home-services purposes from the origin zone i to the destination zone j
- $\varphi^{r,s}$ = Trip generation rates to convert home-work and home-services activity flows to trips

Furthermore, total population in the zone i and employment in the zone j are:

$$H_i = u_i \cdot \sum_j T_{ij}^r \quad (8)$$

$$E_j = E_j^b + E_j^s = E_j^b + \sum_i T_{ij}^s \quad (9)$$

Both the travel pattern and the activity location are determined from Eq. 6 implicitly. Equation 6 looks quite similar to the logit destination choice model, in case the logit utility functions ($V_j^{r,s}$) is:

$$V_j^{r,s} = \ln W_{i,j}^{r,s} - \theta^{r,s} \cdot c_{ij} \quad \forall (i \in I, j \in J) \quad (10)$$

Therefore, the model form of Eq. 6 can be explained within the framework of the random utility theory of users' behavior. The model used to estimate mode choice behavior is the well-known nested logit model as shown below (McFadden, 1974):

$$T_{ijm}^{r,s} = O_{j,i}^{r,s} \frac{W_{i,j}^{r,s} \exp(-\theta^{r,s} \cdot w_{ij}^{r,s})}{\sum_1 W_1^{r,s} \exp(-\theta^{r,s} \cdot w_{ij}^{r,s})} \cdot \frac{\exp(-\mu^{r,s} \cdot c_{ijm})}{\sum_n \exp(-\mu^{r,s} \cdot c_{ijn})} \quad (11)$$

Where:

- $T_{ijm}^{r,s}$ = No. of trips for home-work and home-services purposes from the origin zone i to the destination zone j using mode m
- c_{ijm} = Travel cost from the zone i to the zone j using mode m
- $\mu^{r,s}$ = Empirically estimated parameters
- $w_{ij}^{r,s}$ = The inclusive price (is equal to the natural logarithm of the denominator of the logit mode choice function (Ben-Akiva and Lerman, 1985) has the following form:

$$w_{ij}^{r,s} = -\frac{1}{\mu^{r,s}} \ln \sum_n \exp(-\mu^{r,s} \cdot c_{ijn}) \quad (12)$$

Route choice model: In transportation planning practice, the problem of route choice is traditionally called traffic (or trip) assignment, since Origin-Destination (O-D) flows were viewed as being mechanically assigned to the network. The User-Optimal model (UO) of route choice described in this section is based on Sheffi's (1985) notations. Given a network $G(N,A)$ with N nodes and A links, with a positive monotonically increasing link performance (travel cost) function $c_a(f_a)$ of flow f_a on link $a \in A$, the UO trip assignment distributes the fixed demand $T_{ijm}^{r,s}$ such as no individual can improve his/her route choice. The minimization problem will be:

$$\text{Minimize } Z(f) = \sum_m \sum_a \int_0^{f_a} C_{ma}(z) dz \quad (13)$$

Subject to:

$$f_{ma} = \sum_i \sum_j \sum_p \sum_m \delta_{ijmp}^{r,s} \cdot h_{ijmp}^{r,s} \quad (14)$$

$$\sum_p h_{ijmp}^{r,s} = T_{ijm}^{r,s} \quad \forall (i \in I, j \in J) \quad (15)$$

$$h_{ijmp}^{r,s} \geq 0 \quad \forall (p \in P) \quad (16)$$

Where:

- f_{ma} = Flow of person trips of mode m on link a
- $C_{ma}(Z)$ = Travel cost function of mode m on link a at person flow f_{ma}
- $h_{ijmp}^{r,s}$ = Person trips from i to j by mode m using path p
- $\delta_{ijmp}^{r,s}$ = 1 if the path flow $h_{ijmp}^{r,s}$ uses link a and 0 otherwise

The objective function is to minimize the cumulative system travel cost, which is measured by the sum of the

integral in Eq. 13. Condition 14 describes the connection between link flows and path flows, constraint 15 ensures that all demands are distributed on the network and constraint 16 represents the non-negativity of the path flows.

To show the equivalency, it should be building the Lagrange function of the minimization problem and then solving the KKT conditions for the minimization problem. After solving KKT conditions:

$$c_{ijmp} - u_{ijm} \geq 0 \quad \forall (i \in I, j \in J, m \in M, p \in P) \quad (17)$$

$$h_{ijmp}^{r,s} [c_{ijmp} - u_{ijm}] = 0 \quad \forall (i \in I, j \in J, m \in M, p \in P) \quad (18)$$

Where:

u_{ijm} = Minimum travel cost between i and j by mode m

These equations show that the path flow comes to zero if the associated path travel cost exceeds the minimum travel cost. However, the associated path travel cost is equal to the minimum travel cost, if the path flow is greater than zero.

COMBINED LOCATION, TRIP DISTRIBUTION, MODE AND ROUTE CHOICES MODEL FORMULATION

Overcoming inconsistency among steps leads to the consideration of a combined location, trip distribution, mode and route choices model (CLDMR) with which the problems location and travel choices are solved jointly. The proposed CLDMR is specified as follows:

$$T_{ij}^{r,s} = O_{ij}^{r,s} \frac{W_{i,j}^{r,s} \exp(-\theta^{r,s} \cdot w_{ij}^{r,s})}{\sum_l W_{i,l}^{r,s} \exp(-\theta^{r,s} \cdot w_{ij,l}^{r,s})} \quad (19)$$

$$T_{ijm}^{r,s} = T_{ij}^{r,s} \cdot \frac{\exp(-\mu^{r,s} \cdot u_{ijm})}{\sum_n \exp(-\mu^{r,s} \cdot u_{ijn})} \quad (20)$$

$$c_{ijmp} - u_{ijm} \geq 0 \quad \forall (i \in I, j \in J, m \in M, p \in P) \quad (21)$$

$$h_{ijmp}^{r,s} [c_{ijmp} - u_{ijm}] = 0 \quad \forall (i \in I, j \in J, m \in M, p \in P) \quad (22)$$

$$\sum_p h_{ijmp}^{r,s} = T_{ijm}^{r,s} / \eta^{r,s} \quad \forall (i \in I, j \in J, m \in M) \quad (23)$$

$$h_{ijmp}^{r,s} \geq 0 \quad \forall (p \in P)a \quad (24)$$

$$f_{ma} = \sum_i \sum_j \sum_p \sum_m \delta_{ijmp}^{r,s} \cdot h_{ijmp}^{r,s} \quad (25)$$

Where:

$$w_{ij}^{r,s} = -\frac{1}{\mu^{r,s}} \ln \sum_n \exp(-\mu^{r,s} \cdot u_{ijn}) \quad (26)$$

$$W_i^r = L_{v,i}^m \cdot X_i^n \cdot L_{r,i}^o \cdot \prod_n \left(1 + \frac{H_i^n}{\sum_n H_i^n} \right)^{R_n} \quad (27)$$

$$W_j^s = (E_j^s)^{s'} \cdot L_j^{s'} \quad (28)$$

η = Ratio of occupants to vehicles (persons per vehicle)

In this model Eq. 19-28 constitute a quantitative statement of UE conditions for the CLDMR. Eq. 19-20 determine activity location, trip distribution and mode choice model. Equation 21-22 assign trips to a transportation network according to the UE principle. The condition in Eq. 23 means that number of trips on all paths belong to a given mode's network and connecting a given OD pair equal the total trips distributed from i to j by mode m . The condition in Eq. 24 states that each path flow is non negative nature. The relationship between path and link flows is defined by Eq. 25.

EQUIVALENT MINIMIZATION PROBLEM

One of the important issues in analyzing the combined model is to drive its equivalent optimization problem. The idea of the equivalent optimization problem approach is to construct an intermediate model built around a convenient objective function and the original constraints (or a subset of them) that would permit to recover the model Equations from the conditions of optimality of the minimization or maximization problem (Pietrantonio, 2001). The CLDMR can be formulated as an EMP:

$$\text{Minimize } Z(T,M,f) = G(T) + H(M) + F(f) \quad (29)$$

subject to:

$$\sum_p h_{ijmp}^{r,s} = T_{ijm}^{r,s} / \eta^{r,s} \quad \forall (i \in I, j \in J, m \in M) \quad (30)$$

$$\sum_m T_{ijm}^{r,s} = T_{ij}^{r,s} \quad \forall (i \in I, j \in J) \quad (31)$$

$$\sum_{i,j} T_{ij}^{r,s} = O_{j,i}^{r,s} \quad \forall (i \in I, j \in J) \quad (32)$$

$$h_{ijmp}^{r,s} \geq 0 \quad (33)$$

Where:

$$G(T) = \left(\frac{1}{\theta^{r,s}} - \frac{1}{\mu^{r,s}} \right) \cdot \sum_i \sum_j T_{ij}^{r,s} \cdot (\ln T_{ij}^{r,s} - 1) - \frac{1}{\theta^{r,s}} \sum_i \sum_j T_{ij}^{r,s} \cdot \ln W_{i,j}^{r,s} \quad (34)$$

$$H(M) = \frac{1}{\mu^{r,s}} \sum_i \sum_j \sum_m T_{ijm}^{r,s} (\ln T_{ijm}^{r,s} - 1) \quad (35)$$

$$F(f) = \eta^{r,s} \cdot \sum_{m,a} \int_0^{f_{ma}^{r,s}} C_{ma}^{r,s}(z) dz \quad (36)$$

$$f_{ma}^{r,s} = \sum_i \sum_j \sum_m \sum_p \delta_{ajmp}^{r,s} \cdot h_{ijmp}^{r,s} \quad (37)$$

In this formulation, the objective function (Eq. 29) comprises into three components. The term, $G(T)$, is a function of $T_{ij}^{r,s}$ distributed from a given origin i to a given destination j . The second term, $H(M)$, specifies each term in the set as a function of $T_{ijm}^{r,s}$ distributed from a given origin i to a given destination j by mode m . The function $F(f)$ has as much terms as the number of links in a transportation network. Each term is a function of the traffic flows over all possible paths that share a given link a , which implied by the link-path incidence relationships (Eq. 37).

Equation 30 through 32 are the flow conservation constraints. Equation 33 is the flow non negativity constraints required to ensure the solution of the program physically meaningful.

MODEL PROPERTIES AND CALIBRATION

The analyzing combined model need to prove the equivalence between the proposed combined model and its EMP problem. To proof of the equivalence theorem, we should establish the theorems of existence, convexity, uniqueness and positivity. The proofs of the theorems are not considered in this paper. The theorem of equivalence can be proved based on the Lagrangian equations and the KKT optimality conditions for the EMP when the Lagrangean function is:

$$L(T,M,h) = Z(T,M,f(h)) + \sum_{j,i} \phi_{j,i}^{r,s} \cdot (O_{j,i}^{r,s} - \sum_{i,j} T_{ij}^{r,s}) + \sum_{i,j} \kappa_{ij}^{r,s} \cdot (T_{ij}^{r,s} - \sum_m T_{ijm}^{r,s}) + \sum_i \sum_j \sum_m \gamma_{ijm}^{r,s} \cdot (T_{ijm}^{r,s} / \eta^{r,s} - \sum_p h_{ijmp}^{r,s}) + \sum_i \sum_j \sum_m \sum_p \lambda_{ijmp}^{r,s} \cdot (-h_{ijmp}^{r,s}) \quad (38)$$

where, $\gamma_{ijm}^{r,s}$, $\kappa_{ij}^{r,s}$, $\phi_{j,i}^{r,s}$ and $\lambda_{ijmp}^{r,s}$ denote, respectively, the dual variables associated with the constraints in Eq. 30-33.

The KKT optimality conditions obtained by taking derivatives of this function with respect to $T_{ijm}^{r,s}$, $T_{ij}^{r,s}$, $h_{ijmp}^{r,s}$ are:

$$\frac{1}{\mu^{r,s}} \ln T_{ijm}^{r,s} - \kappa_{ij}^{r,s} + (\gamma_{ijm}^{r,s} / \eta^{r,s}) = 0 \quad (39)$$

$$\left(\frac{1}{\theta^{r,s}} - \frac{1}{\mu^{r,s}}\right) \ln T_{ij}^{r,s} - \frac{1}{\theta^{r,s}} \ln W_{i,j}^{r,s} - \phi_{ij}^{r,s} + \kappa_{ij}^{r,s} = 0 \quad (40)$$

$$\eta^{r,s} \cdot C_{ijmp} - \gamma_{ijm}^{r,s} - \lambda_{j,i}^{r,s} = 0 \quad (41)$$

$$\lambda_{ijmp}^{r,s} (-h_{ijmp}^{r,s}) = 0 \quad (42)$$

$$\lambda_{ijmp}^{r,s} \geq 0 \quad (43)$$

If we assume $T_{ij}^{r,s} > 0$, $T_{ijm}^{r,s} > 0$, $h_{ijmp}^{r,s} > 0$ and perform a little computational effort, we have Eq. 19 through 22 with defining:

$$u_{ijm} = \gamma_{ijm}^{r,s} / \eta^{r,s} \quad (44)$$

Therefore, we see that the EMP is equivalent to the CLDMR.

The next step is to determine the appropriate values of the parameters in order to apply the model.

The computation process used to produce values of parameter estimation involves using gradient-search technique with a Maximum-Likelihood (ML) criterion, which is used to guide the gradient search direction. The ML method is a standard approach for calibrating the values of the logit choice functions parameters (Boyce and Zhang, 1997). According to the numerical tests, Putman (1991) pointed out the gradient approach can efficiently estimate nine parameters simultaneously.

SOLUTION ALGORITHM

Implementation of the CLDMR requires an algorithm for obtaining solutions for the EMP. Because of the EMP is a convex programming problem with linear constraints, it can be solved efficiently by either Evans or Frank-Wolfe algorithm. The Evans algorithm is preferred, because; it requires less iteration than the Frank-Wolfe algorithm in order to obtain suitable solutions. Moreover, each iteration in the Evans algorithm computes an exact solution for the equilibrium conditions, while in the Frank-Wolfe algorithm; none of the equilibrium conditions are not satisfied until the final convergence (Chu, 1999). The last advantage of the Evans algorithm is an important issue in the large-scale network applications, because subject to cost it is often unlikely that either the Evans or the Frank-Wolfe algorithm will be run again and again to find out exact convergence.

The Evans algorithm applied to the EMP can be summarized as follows (Patriksson, 1994):

Step 0: Initialization

Find an initial feasible solution $\{T_{ij,0}^{r,s} = 1, T_{ijm,0}^{r,s} = 1, f_{ma,0}^{r,s} = 0\}$. Set $n = 0$.

Step 1: Travel cost update

Set $C_{ma,n} := C_{ma}(f_{ma,n-1}^{r,s})$, $n = n+1$ and compute minimum cost paths $\{u_{ijm,n}^{r,s}\}$ on the basis of updated link costs, for every O-D pair. Compute $\{w_{ij,n}^{r,s}\}$ based on Eq. 12 as a function of the shortest path costs.

Step 2: Direction finding

- Solve a destination and mode choice models as a function of the shortest path costs $P_{ij,n}^{r,s} = \frac{W_{i,j,n}^{r,s} \exp(-\theta^{r,s} \cdot w_{ij,n}^{r,s})}{\sum_{l,n} W_{l,n}^{r,s} \exp(-\theta^{r,s} \cdot w_{ij,l,n}^{r,s})}$ and $Q_{ijm,n}^{r,s} \cdot Q_{ijm,n}^{r,s} = P_{ij,n}^{r,s} \cdot \frac{\exp(-\mu^{r,s} \cdot u_{ijm,n}^{r,s})}{\sum_k \exp(-\mu^{r,s} \cdot u_{ijk,n}^{r,s})}$ applying the dimensional balancing method
- Perform an all-or-nothing assignment of demand $\{Q_{ijm,n}^{r,s}\}$ to the shortest paths computed with the updated link costs $\{C_{ma,n}\}$. This yields $\{y_{ma,n}^{r,s}\}$. The $P_{ij}^{r,s}$, $Q_{ijm}^{r,s}$ and $y_{ma}^{r,s}$ represent the auxiliary flow, variables corresponding to $T_{ij}^{r,s}$, $T_{ijm}^{r,s}$ and $f_{ma}^{r,s}$, respectively

Step 3: Convergence check

Compute the Lower Bound (LB), Best Lower Bound (BLB) and Relative Gap then test for convergence:

$$\begin{aligned} \text{Gap}_{n-1} &= \eta^{r,s} \cdot \sum_m \sum_a C_{ma}(f_{ma,n-1}^{r,s}) \cdot (y_{ma,n}^{r,s} - f_{ma,n-1}^{r,s}) + \frac{1}{\mu^{r,s}} \sum_i \sum_j \sum_m Q_{ijm,n}^{r,s} \\ & (\ln Q_{ijm,n}^{r,s} - 1) - \frac{1}{\mu^{r,s}} \sum_i \sum_j \sum_m T_{ijm,n-1}^{r,s} \cdot (\ln T_{ijm,n-1}^{r,s} - 1) + \frac{\mu^{r,s} - \theta^{r,s}}{\mu^{r,s} \cdot \theta^{r,s}} \sum_i \sum_j P_{ij,n}^{r,s} \cdot (\ln P_{ij,n}^{r,s} - 1) - \\ & \frac{1}{\theta^{r,s}} \sum_i \sum_j P_{ij,n}^{r,s} \cdot \ln W_{i,j,n}^{r,s} - \frac{\mu^{r,s} - \theta^{r,s}}{\mu^{r,s} \cdot \theta^{r,s}} \sum_i \sum_j T_{ij,n-1}^{r,s} \cdot (\ln T_{ij,n-1}^{r,s} - 1) + \frac{1}{\theta^{r,s}} \sum_i \sum_j T_{ij,n-1}^{r,s} \cdot \ln W_{i,j,n}^{r,s} \\ \text{LB}_{n-1} &= Z(T_{n-1}, M_{n-1}, f_{n-1}) + \text{Gap}_{n-1} \\ \text{BLB} &= \max_{n-1} (\text{LB}_{n-1}) \\ \text{Relative Gap}_{n-1} &= \frac{\text{Gap}_{n-1}}{\text{BLB}} \end{aligned} \quad (45)$$

Is the Relative Gap $< \epsilon$? If YES, STOP; otherwise continue.

Step 4: Step-size determination

Find $\alpha_n^{r,s}$ that solves

$$\begin{aligned} \text{Min } Z(\alpha_n^{r,s}) &= \eta^{r,s} \cdot \sum_m \sum_a [f_{ma,n-1}^{r,s} + \alpha_n^{r,s} (y_{ma,n}^{r,s} - f_{ma,n-1}^{r,s})] C_{ma}(z) dz + \\ & \frac{1}{\mu^{r,s}} \sum_i \sum_j \sum_m [T_{ijm,n-1}^{r,s} + \alpha_n^{r,s} (Q_{ijm,n}^{r,s} - T_{ijm,n-1}^{r,s})] \cdot (\ln [T_{ijm,n-1}^{r,s} + \alpha_n^{r,s} (Q_{ijm,n}^{r,s} - T_{ijm,n-1}^{r,s})] - 1) + \\ & \frac{\mu^{r,s} - \theta^{r,s}}{\mu^{r,s} \cdot \theta^{r,s}} \sum_i \sum_j [T_{ij,n-1}^{r,s} + \alpha_n^{r,s} (P_{ij,n}^{r,s} - T_{ij,n-1}^{r,s})] \cdot (\ln [T_{ij,n-1}^{r,s} + \alpha_n^{r,s} (P_{ij,n}^{r,s} - T_{ij,n-1}^{r,s})] - 1) - \\ & \frac{1}{\theta^{r,s}} \sum_i \sum_j [T_{ij,n-1}^{r,s} + \alpha_n^{r,s} (P_{ij,n}^{r,s} - T_{ij,n-1}^{r,s})] \cdot \ln W_{i,j}^{r,s} \\ & \text{subject to} \\ & 0 \leq \alpha_n^{r,s} \leq 1 \end{aligned} \quad (46)$$

Step 5: Flow update

Revise trip flows as following:

$$T_{ij,n}^{r,s} = T_{ij,n-1}^{r,s} + \alpha_n^{r,s} (P_{ij,n}^{r,s} - T_{ij,n-1}^{r,s}) \quad (47)$$

$$T_{ijm,n}^{r,s} = T_{ijm,n-1}^{r,s} + \alpha_n^{r,s} (Q_{ijm,n}^{r,s} - T_{ijm,n-1}^{r,s}) \quad (48)$$

$$f_{ma,n}^{r,s} = f_{ma,n-1}^{r,s} + \alpha_n^{r,s} (y_{ma,n}^{r,s} - f_{ma,n-1}^{r,s}) \quad (49)$$

Step 6: Convergence check

Retest the updated value of the objective function for convergence. If the Relative Gap is acceptable, STOP; otherwise go to Step 1.

It should be mentioned that the other convergence criterion is needed for the trip table. For the trip table, we consider a simple criterion, the Total Misplaced Flow (TMF), which is the sum of the absolute differences of zone to zone flows in the main problem solution and sub problem solution. If these two tables are equal, the algorithm has converged with regard to the trip table (Boyce and Bar-Gera, 2006).

RESULTS AND DISCUSSION

Integrated urban land use and transportation demand model: The Lowry lineage has been fertilized, during the years, by the economic approach and the demographic approach that could be seen under the urban economics

and the micro-simulation lineage (Pietrantonio, 2001). The efforts driven to integrating these approaches with general network equilibrium framework were successful in a high degree, even without eliminating their identities.

We use the concept of modified Garin-Lowry model by Berechmann and Small (1988) to develop our proposed model.

Figure 1 shows descriptively the proposed model to demonstrate the way in which the economic-base mechanism, the equilibrium activity location and travel choices sub models and the constraint procedure interact. Table 1 present the general steps of the proposed model in the glimpse.

The input data include zonal levels of basic employment, zonal levels of attractiveness for residential and service location, network information, estimated parameters and control parameters of the economic-base mechanism. Based on these inputs, first, the workers in the basic sector are allocated to residential zones with using CRDMR model; this is the step 1 in Table 1.

The iterative computational Evans algorithm will continue until a predefined convergence criterion is satisfied. In this process, after the congested travel cost has been obtained, the minimum-cost path of the network can be determined. The initial trip distribution and the initial modal split pattern are determined using the minimum-cost path, destination and mode estimated parameters and residential zonal attractiveness. Then the residential location choice can be directly obtained. The

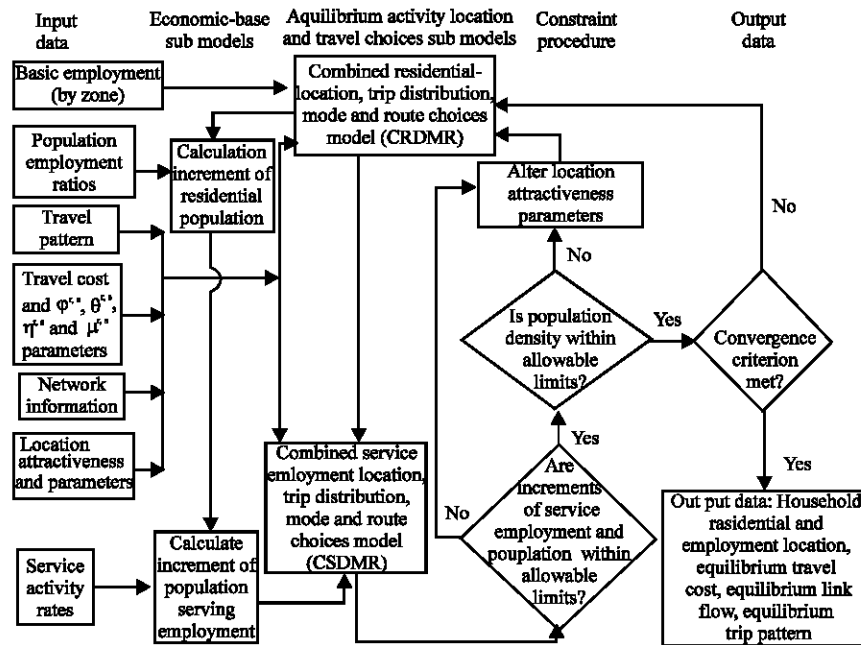


Fig. 1: Flowchart of the proposed combined urban land use and transportation demand model

Table 1: General steps of the proposed model to integrate land use and transportation demand

Steps	Description	Outputs
1	Solve CRDMR model	Initial equilibrium travel cost; equilibrium network link flow; equilibrium trip patterns and equilibrium residential distribution
2	Solve Economic-base sub models	The increments of residential population and population-serving employment
3	Solve CSDMR model	The initial equilibrium travel cost; equilibrium network link flow; equilibrium trip patterns and equilibrium employment distribution

trips are assigned to the transportation network according to the household distribution pattern (the demand of traveling work to home) and the travel cost. The computation will be terminated when an equilibrium travel and residential location choice pattern is obtained. The main outputs of the CRDMR model are initial equilibrium travel cost; equilibrium network link flow; equilibrium trip patterns and equilibrium residential distribution.

Then the incremental residential population and the resulting incremental dependent service employment based on Eq. 8, 9 are calculated (step 2). This increment of employment is distributed to zones of workplace with using CSDMR model (step 3).

The iterative computational Evans algorithm will continue until a predefined convergence criterion is satisfied. In the CSDMR model, the preload traffic on the network which obtained from CRDMR model used as an initial feasible solution. These preload traffic volumes are associated with vehicle trips that are on the network but are not contained in the origin-destination matrix to be assigned (Caliper Corporation, 2002). The remainder of the Evans algorithm used to CSDMR model is similar to which used to the CRDMR model. The initial equilibrium travel cost; equilibrium network link flow; equilibrium trip patterns and equilibrium employment distribution come into view of the CSDMR model outputs.

After step 3, the corresponding increment in population is derived and distributed to zones of residential location with using CRDMR model (step 1). This entire iterative process continues until the economic-base mechanism converges.

In each iteration, a test is used to ascertain that zonal densities of service employment and residential population are within preset bounds. If test fall in:

- False: an iterative procedure (internal to the economic-base iterations) is used to reallocate the latest increments by changing the zonal attraction parameters
- True: the outputs satisfy all convergence criteria and we find out the final solution

The final output of the proposed model includes vectors of residential population and household-dependent employment, equilibrium trip pattern (trip tables), vectors of residential-attractor and service-attractor weights, equilibrium travel cost and equilibrium link flow.

CONCLUSIONS AND MODEL EXTENSIONS

In this study the integrated urban land use and transportation demand model based on Lowry lineage was presented. We considered two combined sub models for the simultaneous prediction of activity location choices, trip distribution, mode choices and route choices. Sub models reformulated as an equivalent minimization problem. We used Evans algorithm to solve both sub models. We applied two sub models, the economic-base mechanism and the constraint procedure to develop a suitable framework of integrated land use and transportation demand model. The proposed model overcomes to three crucial shortcomings in the previous models:

- Consider to network congestion
- Consider to equilibrium combined travel and activity location choices model
- Consider to random utility maximization behavioral theory

To calibrate the proposed model ML method can be used as standard approach. However the Evans algorithm that we justified to solve sub models converge in less iteration rather than the Frank-Wolfe algorithm and in each iteration, we have a feasible solution, in contrast it is not true for the Frank-Wolfe algorithm. Above issues are very important in large scale application.

This research has some potential for future extension. First, there is a need to apply the proposed model to real-world large-scale transportation networks, so that the behavioral richness and computational tractability of the model can be empirically verified. Second, it would be very productive to reformulate the model so that it allows interactions among respective modal networks. Third, it is valuable incorporating trip chaining behavior in proposed integrated model.

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