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TRIP-CHAIN BASED MULTIMODAL TRAFFIC ASSIGNMENT MODEL WITH COMBINED MODES

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ABSTRACT: Existing multimodal traffic assignment models do not give a detailed description of trip-chain analysis with combined modes. This study develops a trip-chain based multimodal traffic assignment model with combined modes, which is helpful for deeper understanding of the multi-modal travel behaviour.

1 INTRODUCTION

With the development of the comprehensive transport infrastructure, people tend to complete a trip by using more than one traffic modal, especially in metropolitan areas. Existing multimodal traffic assignment models lack enough consideration of the trip-chain based traffic behaviour that forms the basis of travel demand in urban areas. The trip chain contains all travel routes which cover one or several activities (many purposes) in a certain time sequence (Lam and Yin, 2001; Liu and Li, 2010), which can reflect the entire travel behaviour in the multimodal transportation network.

2 METHODOLOGY

2.1 Trip-chain based travel route

Consider a multimodal transportation network $G=(N, L)$, where N is the set of nodes and L is the set of links. G constitutes of three sub-networks, several parking and transferring nodes and walking links. The three sub-networks are: car sub-network G_1, bus sub-network G_2 and metro sub-network G_3. W is the set of OD pair, and w is one of the OD pairs. M is the set of traffic modes, and m is one of the traffic modes. Trip chain can be defined as a description of a series of trips linked together between anchor destinations (stops), such as a journey that leaves home, a stop to drop a passenger, continues to work, and returns home at last (Maruyama and Harata, 2006; Higuchi et al., 2011). Temporally and spatially, a trip chain consists of sequential trips containing some stops and links. P is the set of the available trip-chain based travel routes, and p is one of the routes, $p \in P$, which can be expressed by a series of stops as follows:

$$p = \{n_1, n_2, \ldots, n_s, \cdots\} \qquad (1)$$

where s is the number of the stops. For example, the traditional route set in a transportation network as shown in Figure 1 includes three routes $\{l_1, l_2, l_5, l_6\}$, $\{l_1, l_4, l_6\}$, $\{l_1, l_2, l_3\}$. If we assume that the route l_4 is required, the route set only includes $\{l_1, l_4, l_6\}$.
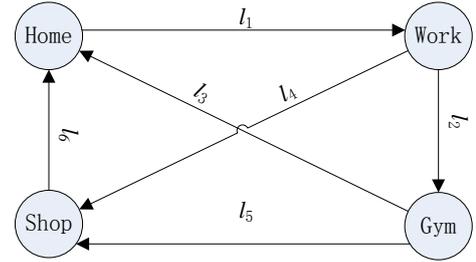

Figure 1 Illustration of trip-chains

2.2 Travel cost

Assume the link travel cost is independent of each other, the route travel cost can be calculated by

$$c_p = \sum_l \delta_{lp} c_l \qquad (2)$$

where c_p is the travel cost on the route p, c_l is the travel cost on the link l. δ_{lp} is the route-link incidence matrix, where $\delta_{lp}=1$ if route p uses link l, and 0 otherwise. Assume the link travel cost contains three parts: travel time, money cost, and comfort cost, $c_l=t_l+p_l+u_l$, the detailed expressions being given in Table 1.

Table 1 Travel cost function

link	time	money	comfort
car	$T_l^1 = t_l^{01}\left[1+\alpha\left(\dfrac{v_l}{C_l}\right)^{\beta}\right]$	$P_l^1 = \eta\rho x_l$	$U_l^1 = \lambda s^1 T_l^1$
bus	$T_l^2 = t_l^{02}$	$P_l^2 = \cos t^2$	$U_l^2 = \lambda s^2 T_l^2$
metro	$T_l^3 = t_l^{03}$	$P_l^3 = \cos t^3$	$U_l^3 = \lambda s^3 T_l^3$
*trans	$T_l^h = t_l^{0h} + t_l^{1h}$	$P_l^h = 0$	$U_l^h = \gamma T_l^h$

*trans: transfer link t_l^{01}: free-way travel time; t_l^{02}, t_l^{03}: the schedule travel time for bus and metro; t_l^{0h}, t_l^{1h}: the walking time and the waiting time; v_l and C_l; the traffic volume and the capacity; η, λ, γ: the dimensional transformation parameters; ρ: fuel cost; x_l: the length of the link l; cost: the ticket charge; s: the unit comfort loss.

2.3 Equilibrium condition

The traffic equilibrium condition can be analysed based on the Logit model as follows:

$$q_w^m = q_w \frac{\exp(-\theta_1 \varphi_w^m)}{\sum_{m \in M} \exp(-\theta_1 \varphi_w^m)}, m \in M, w \in W \tag{3}$$

$$f_w^p = q_w^m \frac{\exp(-\theta_2 c_w^p)}{\sum_{p \in P_w^m} \exp(-\theta_2 c_w^p)}, p \in P_w, m \in M, w \in W \tag{4}$$

where q_w^m is the traffic demand for travel mode m; f_w^p is the traffic flow on route p; q_w is the total traffic demand between OD pair w; θ_1, θ_2 are the correction parameters; φ_w^m is the expected minimum traffic cost, which can be calculated by:

$$\varphi_w^m = -\frac{1}{\theta_2} \ln \sum_{p \in P} \exp\left(-\theta_2 c_p\right) \tag{5}$$

The traffic demand, traffic flow should be satisfied the following constraints:

$$\sum_{p \in P} f_w^p = q_w^m, m \in M, w \in W \tag{6}$$

$$\sum_{m \in M} q_w^m = q_w, w \in W \tag{7}$$

$$f_w^p \geq 0, p \in P_w, w \in W \tag{8}$$

$$q_w^m > 0, m \in M, w \in W \tag{9}$$

$$q_w > 0, w \in W \tag{10}$$

2.4 Traffic model

The traffic model is formulated based on the variational inequality theory as follows:

$$\sum_{w \in W} \{ \sum_{m \in M} [\sum_{p \in P_w^m} \left(\hat{c}_w^p(f^*, q^*)(f_w^p - f_w^{p*}) \right) + \frac{1}{\theta_1} \ln \frac{q_w^{m*}}{q_w^*}(q_w^m - q_w^{m*})] - G_w^{-1}(q_w^*)(q_w - q_w^*) \} \geq 0 \tag{11}$$

where $\hat{c}_w^p(f^*, q^*) = c_w^p(f^*, q^*) + \frac{1}{\theta_2} \ln \frac{f_w^{r*}}{q_w^{m*}}$, $G_w^{-1}(q_w^*)$ is the inverse function of traffic demand. The feasible region is $\Omega = \{(6)-(9)\}$。

3. SOLUTION ALGORITHM

A solution algorithm for solving the proposed model is given based on MSWA (Method of Successive Weight Averages, MSWA) (Liu et al., 2009). The difference between MSWA and traditional MSA (Method of Successive Averages) is that the iteration step size of MSWA is not a fixed value, but gives more weight to the later iteration points which will speed up the convergence. Specific steps are as follows:

Step 1: Initialization. Set the iteration $n=1$, the link flow is $v_l^{(0)} = 0$;

Step 2: Calculate the link travel cost and the route travel cost, obtain the shortest route and its cost;

Step 3: Determine the effective route which has two conditions: the transfer link is less than the pre-set number, and the route must go through the obligatory node;

Step 4: Calculate the expected minimum traffic cost and the traffic demand, assign the traffic flow based on the Logit model, and then obtain the auxiliary traffic flow $y_l^{(n)}$;

Step 5: Calculate the traffic flow by using MSWA method as follows, where $d=1$.

$$v_l^{(n+1)} = v_l^{(n)} + \chi^{(n)}(y_l^{(n)} - v_l^{(n)}) \tag{12}$$

$$\chi^{(n)} = \frac{n^d}{1^d + 2^d + 3^d + \cdots + n^d} \tag{13}$$

Step 6: Convergence judgement. If the judgement index is less than the pre-set value, then stop, otherwise $n=n+1$ and go back to Step 2.

4. CONCLUSIONS

Traditional multimodal four-step traffic planning model treats the trip as separate, independent entities and lacks the consideration of linkage among trips. This study develops a trip-chain based multimodal traffic assignment model with combined modes. A solution algorithm is developed to solve the trip-chain based equilibrium model, which is based on the method of successive averages. The findings contribute to understand the travel behaviour and lay the foundation for the development of more realistic traffic assignment model.

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