MODELING IMPACTS OF ADVANCED TRAVELER INFORMATION SYSTEM ON PARK AND RIDE BEHAVIOUR

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Abstract: This paper proposes a multi-class probit-based stochastic network equilibrium formulation for modeling the effects of Advanced Traveler Information System (ATIS) in a multimodal transportation network. It can be formulated as a Variational Inequality (VI) problem and solved by a simulation-based heuristic algorithm. It is assumed in this paper that commuters can complete their journeys by three options: using auto mode, walk-metro mode or the park and ride (P&R) mode. And the commuters, which are classified into two types of equipped and unequipped with ATIS, would both make their travel choices following a probit-based stochastic manner. The ATIS is consisted of Route Guide System (RGS) and Parking Information System (PIS) which aid commuters’ decision making on route choice and parking lot choice. The relationship between ATIS service level and its market penetration is also considered. Numerical results show that (1) the equipped users prefer auto mode while the unequipped users prefer to metro mode. (2) The improvement of ATIS service draw more commuters to auto mode. (3) Parking lots with high service level swarm with users equipped with ATIS who supplant the unequipped users. (4) And the numerical analysis also tells that there are opposite actions between RGS and PIS to the sharing ratio of P&R mode. This study is helpful for explicitly evaluating the impacts of ATIS services in multimodal network.

Key words: traffic engineering; multimodal stochastic networks; network equilibrium; VI problem; ATIS

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Intelligent Transportation System (ITS) is publicly known to be one of the brightest prospects of Transportation Industry, where Advanced Traveler Information System (ATIS) is a core component. ATIS, which is generally consisted of Route Guide System and Parking Information System, helps users make choice of a travelling plan with the maximum utility with providing information about traffic status in the network.

Present researches about ATIS’s effects on travelling behavior were mainly focused on subjects of route choice or parking choice, separately. It is noteworthy that Li Zhi-chun (2005) [4] simultaneously modeled impacts of ATIS on both route choice and parking choice. And Tan Zhi-jia[5] furthermore introduced a park and ride (P&R) system and estimated ATIS’s impacts on mode choice, route choice and parking choice in the multimodal network.

However, these works above overlooked travelling costs produced by network uncertainty or non-reliability, as well as ignored the direct relationship between ATIS service level and its market penetration which have been proved crucial to travelling decision-making. Arnott, R. et al. (1999) [7] and Hendrickson, C. et al. (1981) [8] revealed that network uncertainty might resulted in notable delays. Regarding the market penetration, like any commodity in the market, consumer number of ATIS is mainly decided by the products’ service level. Thus, it is not realistic to treat market penetration as a constant variable in the above researches.

So, on the basis of previous works above, several expansions are made in this paper:

(1) Network uncertainty and delay costs are explicitly modeled by way of dividing commuters’ travel disutility function expression into parts of Schedule Cost and Planning Cost.

(2) Endogenous market penetration model is introduced to portray the interaction of ATIS service level and the number of consumers.

And the Stochastic User Equilibrium (SUE) conditions are formulated by a Variational Inequality (VI) model which is solved a combination algorithm of Monte Carlo (MC) method and Method of Successive Average (MSA). In the proposed model, commuters equipped and unequipped with ATIS can complete their journeys by three modes: auto mode, walk-metro mode and the P&R mode (i.e. auto-metro option). Besides, three types of information components of ATIS are considered to seize impacts on the demand distribution in the multimodal network.

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1 ASSUMPTIONS

Consider a multimodal transportation network \( G = (N, L) \), where \( N \) is the set of nodes, including origins, destinations and intermediate nodes of trips, and \( L \) is the set of links connecting nodes. The multimodal transportation network \( G \) is composed of auto-sub-network \( G_a = (N_a, L_a) \), metro sub-network \( G_b = (N_b, L_b) \), the set of transfer points, the set of parking lots and the walking links. Let \( R \) and \( S \) be the sets of origins and destinations of trips, respectively. Then we have \( r \in R \subset N, s \in S \subset N \). And the set of all feasible parking lots between OD pair \((r, s)\) is presented by \( I_{rs} \), \( i \in I_{rs} \); \( T_{rs} \) denotes the set of all possible P&R sites between OD pair \((r, s)\), \( t \in T_{rs} \). Let \( m \) express the set of travel mode, \( m \in \{a, b, c\} \), where \( a \) represents auto mode, \( b \) represents walk-metro mode, \( c \) represents P&R mode (auto-metro in this paper). A number of basic assumptions are adopted in our study as follows, to facilitate formulation of the essential ideas:

A.1 Suppose the study period to be a one-hour period, for example the morning peak hour period. That means, the proposed model is developed by way of static approaches which would be adapted to long-term estimations of transportation planning and management policies (in this paper is effects of ATIS).

A.2 In the reality, there are various irregular and random events occurring on the auto network, such as traffic accidents, vehicle breakdowns, signal failures, adverse weather. Thus, it is assumed in this study that the link travel time \( c_i \) and the parking searching time \( \zeta_j \) in the auto sub-network are stochastic variables following independent normal distribution, i.e., \( c_i \sim N(\tau_i, (\rho_i \tau_i)^2) \) and \( \zeta_j \sim N(d_j, (\lambda_j d_j)^2) \), where \((\rho_i, \lambda_j)\) reflects stochasticity of auto sub-network. As for metro sub-network \( G_b \), which can be treated as a deterministic system with exclusive rails, computer-control trains and planned timetables, the in-vehicle time \( h_i \) in \( G_b \) is a predefined variable in this paper.

A.3 There are two user classes: commuters equipped and unequipped with ATIS services (respectively denoted by superscript \( o(1, 2) \) hereinafter). With assistance of ATIS, the equipped users make the best choice of trip options, whereas the unequipped users make travel decision according to their own perceptions of trip travel time which might be derived from their experiences or from colleagues told. Considering the technical limits and real-world complexity, the information produced by ATIS can not be perfectly precise. Thus, both user classes of commuters make their travel choice following a probit-based stochastic manner under principle of minimum expected disutility.

A.4 Referring to Tan Zhi-jia [5], the travel information produced by ATIS is classified into three types: (i) route guidance information providing the service status of the auto sub-network, for instance by way of route travel time estimation; (ii) parking guidance information including locations of parking facilities (in this paper are parking lots and P&R facilities), available parking space and parking fee; (iii) and the metro information involving service schedules / frequencies, fare and congestion status by metro lines. Users equipped with ATIS are provided by a combination of the three types of information with regard to certain travel modes. And it is reasonable to suppose ATIS’s service displays different in the quality of information. As stated above, the metro information would perform perfectly. And conversely, the route guidance information is provided with the lowest level of service (LOS) since the unpredictable uncertainty of road traffic. Comparatively, the performance of parking guidance information ranges between the other two types.

A.5 The market penetration of ATIS devices, which is defined as the percentage of users equipped with the system, is assumed to be determined by the service charge and users’ profits in form of a decreasing function and an increasing function, respectively [10].

2 SUPPLY FUNCTION

To capture the impacts of network uncertainty on travelers’ behaviors, Noland, R.B. et al. (1998) [9] explicitly formulated the travel disutility by a summation of Schedule Cost and Planning Cost.

The schedule cost includes route travel time, parking search time, parking fee, metro fare, walking time and so on. And the planning cost is quantified by the standard deviation of trip’s total travel time to represent inefficient cost for travelers resulted from uncertainty, such as an additional time margin to hedge against travel time variability and avoid late arrivals or the cost of schedule delay to ensure activities could be conducted punctually with worry about inability to arrive in time.

So, the schedule cost of auto mode, walk-metro mode and P&R mode can be expressed respectively as followings
Let $q^{n,a}_{n,i}$ be the actual schedule cost of user class $n$ ($a=1, 2$) who travel by mode $a$ (auto mode) along path $p$ from origin $r$ to parking lot $i$ in the auto sub-network and then access destination $s$ on foot. It can be formulated as:

$$q^{n,a}_{n,i} = \alpha_i T^a_{n,i} + \alpha_2 z_i^n + \alpha_3 w_i \quad \forall p \in P^a_{n}, \quad i \in I_{n,s}, \quad r \in R, \quad s \in S \tag{1}$$

Where the coefficients ($\alpha$) are reciprocal substitution factors between monetary and temporal cost components; $T^a_{n,i}$ is the travel time of user class $n$ who travel by mode $a$ between origin $r$ and parking lot $i$ via path $p$; $z_i^n$ is the parking time of user class $n$ for an idle parking space in parking lot $i$; $z_i$ is the parking charge at parking lot $i$; $w_i$ is the waking time between parking lot $i$ and destination $s$.

The actual schedule cost $q^{n,b}_{n,i}$ for commuters of user class $n$ using mode $b$ (walk-metro mode), can be computed as

$$q^{n,b}_{n,i} = \beta_i w_i^b + \beta_2 T^b_{n,i} + \beta_3 T^{n,b}_{n,i} + \beta_4 w_i^b + \tau_{n,p} + \Delta^b \quad \forall p \in P^{b}_{n}, \quad r \in R, \quad s \in S \tag{2}$$

Where the coefficients ($\beta$) are reciprocal substitution factors between different cost components; $w_i^b$ and $w_i$ are respectively the waking time of access from origin $r$ to metro station and of egress from metro terminus to destination $s$. $T^b_{n,i}$ is the passengers’ waiting time at metro station nearby origin $r$ which can be computed as Li Z. C. et al.(2007) did[11]; $T^{n,b}_{n,i}$ is the in-vehicle travel time of user class $n$ between origin $r$ and destination $s$ via metro line $p$; $\tau_{n,p}$ is the metro fare per passenger along metro path $p$ between $r$ and $s$; $\Delta^b$ is the additional penalty of travel inconvenience by transferring from walk to metro.

For those commuters of user class $n$ travelling by mode $c$ between origin $r$ and destination $s$ via parking at P&R site $t$, and then boarding at metro station $t'$, their actual schedule cost $q^{n,c}_{n,i}$ can be expressed as:

$$q^{n,c}_{n,i} = \rho_i T^{n,c}_{n,i} + \rho_2 \xi_i^n + \rho_3 \tau_{n,p}^c + \Delta^c \quad \forall p \in P^{c}_{n}, \quad t \in T_{n,s}, \quad r \in R, \quad s \in S \tag{3}$$

Where the coefficients ($\rho$) are the reciprocal substitution factors; $T^{n,c}_{n,i}$ is the travel time from origin $r$ to P&R facility $t$ via path $p$ in auto sub-network and $T^{n,c}_{n,i}$ is the in-vehicle travel time between metro station and destination $s$ via metro line $p$ in metro sub-network; $\Delta^c$ is the additional penalty of transferring from auto to metro by P&R; $\xi_i^n$ is the park-and-ride cost of user class $n$ which is given by

$$\xi_i^n = \kappa_1 \xi_i^n + \kappa_2 z_i + \kappa_3 w_i + \kappa_4 T_i \quad \forall (t, t')$$

Where the coefficients ($\kappa$) are conversion factors between cost components; $z_i$ is the parking charge at P&R facility $t$. $w_i$ is the waiting time from P&R facility $t$ to metro station $t$; $T_i$ is the waiting time at metro $t$ station.

Following Noland et al. (1998), the expected travel disutility of user class $n$ by travel mode $m$ is the combination of schedule cost and travel time cost, that is given by

$$U^{m}_{n,i} = g E[q^{n,m}_{n,i}] + \theta \sigma^{n,m}_{n,i} \quad \forall p \in P^m_{n}, \quad j \in I_{n,s} \cup T^m_{n,s}, \quad r \in R, \quad s \in S \tag{5}$$

Where $E[\cdot]$ returns the expected value of a stochastic variable (detailed computation can be found in works of Li Z. C. et al.(2007) [11]); the schedule cost $q^{n,m}_{n,i}$ can be gained by equation (1-3); $\sigma^{n,m}_{n,i}$ denotes the planning cost resulted from network uncertainty, which can be quantified by

$$\sigma^{n,m}_{n,i} = \sqrt{\sum_{j=1}^{k} (\sigma_{i,j}^n)^2 \delta_{ij}^p + (\sigma_{j,i}^n)^2}, \quad \text{where} \quad \sigma_{i,j}^n \text{ and } \sigma_{j,i}^n \text{ are the standard deviation of user class } n \text{’s travel time on link } l \text{ in auto sub-network and of parking searching time in parking facility } j \text{ (parking lot or P&R facility), respectively; } \delta_{ij} \text{ is the indicator factor that equals 1 if link } l \text{ belongs to path } p \text{ and 0 otherwise; coefficients } g \text{ and } \theta \text{ represent commuters’ value of time (VOT) and value of reliability (VOR) respectively [Small, 1992].}$

### 3 Demand Function

According to assumption A.3, both of the predicated expected travel disutility (ETD) of users equipped with ATIS and the perceived ETD of unequipped users can be formulated as the sum of a systematic component and a stochastic term, i.e.,

$$U^{m}_{n,i} = U^{m}_{n,i} + \lambda (\xi^{n}_{n,i} + \varepsilon^{n}_{i}) \quad \forall p \in P^m_{n}, \quad r \in R, \quad s \in S \tag{6}$$
Where $U_{m,p}^n$ is the systematic term which can be gained by equation (5); $\xi_{n,p}^m, e_{n,j}$ are prediction error terms or perception error terms of user class $n$ about expected route travel time and expected parking searching time respectively; The VOT coefficient $\lambda$ converts the error terms from temporal units to disutility units.

Based on assumption A.4, commuters make their travel choice decision under minimum disutility principle, including mode choice, parking facility choice and route choice. Let $P_{m,p}^n$ be the probability that user class $n$ choose mode $m$, path $p$ and parking facility $j$ for travel between origin $r$ to destination $s$.

$$P_{m,p}^n = \Pr \{ \hat{U}_{m,p}^n < \hat{U}_{m,p}^n | \forall n \neq h, k \neq j, g \neq p \}, \text{ if } m = h, j, k = 0. \quad (7)$$

Where $P_{m,p}^n$ is dependent on the probability distribution of the random variable of link travel time in auto subnetwork $\xi_{n,j}$ and the error term of parking searching time $e_{n,j}$. In this paper, it is assumed that $\xi_{n,j}$ and $e_{n,j}$ follow a normal distribution with zero mean, respectively, i.e., $\xi_{n,j} \sim N(0, (\nu_j^m)^2)$ and $e_{n,j} \sim N(0, (\eta_j^m)^2)$, where $(\nu_j^m, \eta_j^m)$ are constant factors related to link $j$ and parking facility $j$ respectively, which reflect level of service (LOS) of ATIS and unequipped users’ familiarity with traffic status; the higher values of $(\nu_j^m, \eta_j^m)$ are, the worse LOS of ATIS served and the more inexperienced commuters are, vice versa. Therefore, it is easy to conclude that the random term of equation (6) also follows a normal distribution (additivity property of norm distribution). Hence, the route flow can be formulated as,

$$f_{r,s}^m = q_{r,s}^m P_{r,s}^m, \forall p \in I_r, j \in I_s \cup T_s, r \in R, s \in S. \quad (8)$$

Where $q_{r,s}^m$ is the total demand of user class $n$ between OD pair $(r, s)$.

### 4 Network Equilibrium Model and Algorithm

#### 4.1 A Variational Inequality Model

On links of auto sub-network, there are interactions between traffic flows of mode $a$ and $c$, which is not probably symmetrical. Accordingly, a Variational Inequality (VI) model is developed equivalently to the above Stochastic User Equilibrium (SUE) conditions (6–9).

$$\sum_n \sum_m \sum_{p \in I_r} G_{r,s}^m \left( f_{r,s}^m - f_{r,s}^m \right) \geq 0, \forall r \in R, s \in S, n, m, j \in I_r \cup T_s. \quad (9)$$

Where following Ran B. (1996) [12], $G_{r,s}^m$ can be given by $G_{r,s}^m = \left( f_{r,s}^m - q_{r,s}^m P_{r,s}^m \right) \partial U_{r,s}^m / \partial f_{r,s}^m$; the set of feasible solution $\Omega^*$ is composed of non-negativity constraints of route flows and flux conservations between OD pairs, $\Omega^* = \left\{ f^m \left| f_{r,s}^m \geq 0, \sum_n \sum_m \sum_{p \in I_r} f_{r,s}^m = q_{r,s}^m \right. \right\}$.

**Theorem 1** flow pattern in the proposed multimodal stochastic network with multiple user classes under ATIS reaches the stochastic user equilibrium state if and only if it satisfies the VI condition above (9).

The equivalence proof can be referred to Harker (1998), Huang and Lam (2002, 2003). Note that all functions of VI model (9) are continuous about route flows. Hence, there is at least one solution for VI problem (9), according to Brouwer’s fixed-point theory. However, the indicator factors involved in the proposed model lead to nonlinearity and non convexity. Therefore, it is necessary to point that there may be several local optimal solution of the VI problem (9).

#### 4.2 Algorithm

The market penetration plays a remarked role in commuters travel choice and network performance [6]. Yang (1998) introduced an endogenetic model to capture the impacts of LOV of ATIS which was further expanded in Lo and Szeto’s works (2002, 2004), and can be computed as

$$q_{r,s}^m = Q_{r,s} \left[ \left( 1 + \exp \left( C_{r,s} - \phi_{r,s}^m \right) \right) \right], \forall r \in R, s \in S; \quad (10)$$

$$q_{r,s}^m + \phi_{r,s}^m = Q_{r,s}, \forall r \in R, s \in S. \quad (11)$$

Where $q_{r,s}^m$ and $\phi_{r,s}^m$ are respectively the number of users equipped with ATIS and users without ATIS between OD
pair \((r, s)\); \(Q_{rs}\) is the total demand between OD pair \((r, s)\); \(C_N\) is service charges of ATIS; \(\phi_{rs}^1\) denotes the benefits of ATIS, we make use of the reduction of travel disutility of users equipped with ATIS comparing with users without ATIS, which is defined as
\[
\phi_{rs}^1 = \theta \left[ \sum_m \sum_p p_{m, r}^2 u_{m, r}^\lambda - \sum_m \sum_p p_{m, r}^1 u_{m, r}^\lambda \right], \quad \forall r \in R, s \in S.
\] (12)

The Monte Carlo (MC) approach is adapted in this study to simulate auto sub-network’s uncertainty, prediction error of ATIS service and perception error of users without ATIS. And the method of successive average (MSA) is integrated to solve the proposed VI problem (9). The step-by-step procedure of the heuristic algorithm is given below

**Step 1** Initiation. Set for-loop variable \(e = 1\). Choose initial path flows \(f_1^{(e)}\) and \(f_2^{(e)}\) for two types of users. And initial market penetration is given, i.e., 12.5%.

**Step 2** Outer loop operation. Start sampling, set \(k = 1\).

**Step 3** Inner loop operation. Start stochastic network loading.

**Step 3.1** Calculate the link flows \(v_a^{(k)}\) in auto sub-network and \(v_b^{(k)}\) in metro sub-network, and then the expected link travel time \(\tau_a^{(k)}\), \(\tau_b^{(k)}\) and the expected parking searching time \(d_a^{(k)}\), respectively.

**Step 3.2** Perform the MC approach to sample \(\xi_a^{(k)} \sim N(0, (\eta_a^{(k)} \tau_a^{(k)})^2)\) and \(\xi_b^{(k)} \sim N(0, (\eta_b^{(k)} d_a^{(k)})^2)\) for each auto link, parking lot and P&R site. Calculate the predicted expected travel disutility \(U_1^{(k)}\) and the perceived expected travel disutility \(U_2^{(k)}\).

**Step 3.3** Adapt the all-or-nothing assignment, and yield the auxiliary path flows \(g_1^{(k)}\) and \(g_2^{(k)}\) for equipped and unequipped users between OD pair \((r, s)\) with demand \(q_{rs}^{(k)}\) and \(q_{rs}^{(k)}\).

**Step 3.4** Update the auxiliary path flows using the MSA, \(g_1^{(k)} = [(k-1)g_1^{(k-1)} + g_1^{(k)}]/k\) and \(g_2^{(k)} = [(k-1)g_2^{(k-1)} + g_2^{(k)}]/k\).

**Step 3.5** Stop test for the inner sampling loop. If the sample number \(k\) is less than a pre-specified sample size, then let \(k = k + 1\) and go to Step 3.1; otherwise, set \(g^{(e)} = g^{(k)}\) and go to Step 4.

**Step 4** Outer update. Update the path flows by \(f^{(e+1)} = f^{(e)} + (g^{(e)} - f^{(e)})/e\) and the benefits of ATIS service \(\phi_{rs}^{(e+1)}\) by equation (12). Then, yield the market penetration of ATIS \(q_{rs}^{(e+1)}\) and \(q_{rs}^{(e+1)}\) by equations (10–11).

**Step 5** Convergence check. If the following convergence condition (13) is met, then stop and report the solution; otherwise, let \(e = e + 1\) and go to Step 2.
\[
G = \frac{\|f_1^{(e+1)} - f_1^{(e)}\|}{\|f_1^{(e)}\|} + \frac{\|f_2^{(e+1)} - f_2^{(e)}\|}{\|f_2^{(e)}\|} + \frac{\|q_{rs}^{(e+1)} - q_{rs}^{(e)}\|}{\|q_{rs}^{(e)}\|} < \varepsilon.
\] (13)

Where \(G\) is the relative gap between two iterations; \(\varepsilon\) is a pre-specified precision.

5 Numerical Experiments
5.1 Experiment Settings

An example multimodal network is adopted to illustrate the application of the proposed research framework on travel behavior analysis. The example network consists of two OD pairs (1-3 and 2-3) and 11 nodes, as shown in Figure 1. Nodes 1 and 2 represent residential zones which are located in suburban area. Node 3 represents the central business district (CBD) in urban area. Nodes A and B represent two parking lots located within the CBD area. P&R sites 1 and 2 are located nearby node 5. Commuters travel between residential area and the CBD area mainly by three alternative modes which are auto, walk-metro and auto-metro via transferring at P&R sites.

The link travel time \(t_l(v)\) in auto sub-network is estimated by the following Bureau of Public Roads (BPR) function
\[
t_l(v) = \theta_l \left(1 + 0.15(v/C_l)^4\right) \quad \forall l \in L_a
\] (14)

Where \(\theta_l\) and \(C_l\) are respectively the free-flow travel time and capacity on link \(l\).

Let the searching time for a parking space be computed by the following BPR-type function (Lam et al., 1999)
\[ d_j(v_j) = d_j^0 + 0.31 \left( \frac{v_j}{C_j} \right)^{4/3}, \quad j \in J_n \cup T_n \]  

(2.11)

Where \( d_j^0 \) and \( C_j \) are the free-flow parking searching time and the number of parking spaces supplied at parking facility \( j \). \( v_j \) is the parking demand at parking site \( j \).

![Fig. 1. The example network](image)

Parameters involved in our models are given in Table 1.

<table>
<thead>
<tr>
<th>Auto link</th>
<th>( \delta_j^A ) (h)</th>
<th>( C_j ) (veh/h)</th>
<th>Auto link</th>
<th>( \delta_j^B ) (h)</th>
<th>( C_j ) (veh/h)</th>
<th>Walk link</th>
<th>Travel time (h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1, 5)</td>
<td>0.15</td>
<td>800</td>
<td>(1, 8)</td>
<td>0.15</td>
<td>600</td>
<td>(1, 4)</td>
<td>0.40</td>
</tr>
<tr>
<td>(1, 8)</td>
<td>0.65</td>
<td>800</td>
<td>(7, 8)</td>
<td>0.15</td>
<td>600</td>
<td>(2, 4)</td>
<td>0.40</td>
</tr>
<tr>
<td>(2, 5)</td>
<td>0.20</td>
<td>800</td>
<td>(7, 9)</td>
<td>0.40</td>
<td>800</td>
<td>(5, 6)</td>
<td>0.05</td>
</tr>
<tr>
<td>(2, 9)</td>
<td>0.70</td>
<td>800</td>
<td>(8, 10)</td>
<td>0.25</td>
<td>800</td>
<td>(11, 3)</td>
<td>0.20</td>
</tr>
<tr>
<td>(5, 7)</td>
<td>0.30</td>
<td>800</td>
<td>(9, 10)</td>
<td>0.25</td>
<td>800</td>
<td>(A/B, 3)</td>
<td>0.10</td>
</tr>
</tbody>
</table>

In this numerical experiment, it is assumed that metro fare is \( \$ 0.4 \) per unit distance, and the lengths of metro link (4, 11) and (6, 11) are 45km and 36km, respectively. The average travel time by metro is 60km/h. And the vehicle capacity and dispatching frequency of the metro system are 400 passenger per vehicle and 6 vehicles per hour, respectively.

The parking capacity and free-flow parking search time for parking lot A and B within CBD are both 0.1hour and 750vehicles; whereas P&R sites 1 and 2 are both 0.05hour and 400 vehicles. The parking fee are \( \$ 12 \) at parking lot within CBD and \( \$ 2 \) at P&R sites nearby node 5.

As stated by assumption A3, the prediction error of RGS \( \nu_j^r = 0.2 \), the prediction error of PGS \((\eta_{P&R}^A, \eta_{P&R}^B) = (0.15, 0.05)\) and \((\eta_A^l, \eta_B^l) = (0.15, 0.05)\), respectively; ATIS service charges \( \$ 0.02 \) per time.

Other model parameters are \( \alpha_1 = 1.0, \quad \alpha_2 = 1.4, \quad \alpha_3 = 0.1, \quad \alpha_4 = 1.8; \quad \beta_1 = 1.8, \quad \beta_2 = 2.0, \quad \beta_3 = 1.0; \quad \rho_1 = 1.0, \quad \rho_2 = 2.0, \quad \rho_3 = 1.0; \quad \kappa_1 = 0.7, \quad \kappa_2 = 0.1, \quad \kappa_3 = 0.9; \quad \theta = 1.0, \quad \mu = 0.3 \) and \( \gamma = 1.0 \). Besides, the additional penalty parameters are 0.1 and 0.2 for walk-metro and P&R mode, respectively; the stochasticity of network is given by \((\sigma_j, \sigma) = (0.5r_j, 0.3d_j)\); and perception error factors of unequipped users are \((\nu_j^2, \eta_j^2) = (0.6, 0.4)\).

The MC sampling size \( \kappa = 2000 \). And the demand between OD pair (1, 3) and (2, 3) are denoted as \( q_{13} = 2000 \) (passenger/h) and \( q_{23} = 1000 \) (passenger/h).
\section{Numeric Analysis}

\begin{figure}[h]
\centering
\includegraphics[width=0.5\textwidth]{convergence.png}
\caption{The convergence of the proposed solution algorithm}
\end{figure}

Figure 2 displays the convergence of the proposed solution algorithm. It can be seen that the $G$-value (the left part of equation 13) decreases fast in a jagged manner and becomes very small (<0.001) after 200 iterations, thus $\mathbf{f}^{(n+1)}$ approaches to the solution of the present VI problem (9). This convergence pattern as shown in Figure 2 can be explained by the fix steplength adapted in our MSA.

Table 2 depicts impacts of PGS with different LOS on commuters’ parking behaviors. As given higher LOS about P&R2 and Parking lot B ($\eta_{P&R2}^i = \eta_{02}^i = 0.05$), the two locations are favored by most of users equipped with ATIS. As for unequipped users, though their perception about all parking facilities makes no difference, they turn to prefer P&R1 and Parking lot A to P&R2 and Parking lot B which are fluxed with user class 1.

\begin{table}[h]
\centering
\caption{Effects of PGS on users’ parking choice}
\begin{tabular}{|c|c|c|c|c|c|}
\hline
OD pair & User class & P&R choice(100% in total) & Parking choice(100%in total) & Parking lot A(%) & Parking lot B(%) \\
& & P&R1(%) & P&R2(%) & & \\
\hline
OD13 & 1 & 22.68 & 77.32 & 31.28 & 68.72 \\
& 2 & 72.27 & 27.73 & 52.47 & 47.53 \\
OD23 & 1 & 36.66 & 63.34 & 28.89 & 71.11 \\
& 2 & 63.78 & 36.22 & 46.75 & 53.25 \\
\hline
\end{tabular}
\end{table}

The assessment of the impacts of ATIS on commuters’ disutility is presented in the following Table, where coefficients $(\omega_j^i, \eta_j^i)$ decrease from $2^*(0.2, 0.1)$ to $0^*(0.2, 0.1)$ indicating an increase of LOS of ATIS. Table 3 shows shifts of components of the expected travel disutility of equipped users resulted from ATIS. It can be observed that the expected travel disutility of equipped users reduces to $\text{Y} 2.74$ from $\text{Y} 2.88$ due to remarkable decrease of the trip’s planning cost while LOS of ATIS improves. Table 3 also shows that the improvement of LOS brings consumers more benefits of ATIS, which is defined as reduction of travel disutility and calculated by equation (12).

\begin{table}[h]
\centering
\caption{The expected travel disutility of equipped users resulted from ATIS}
\begin{tabular}{|c|c|c|c|c|c|c|}
\hline
LOS of ATIS & Expected travel & Schedule cost & Planning cost & Benefits of ATIS \\
& disutility(\text{Y/passenger}) & (\text{Y/passenger}) & (\text{Y/passenger}) & (\text{Y/passenger}) \\
& OD13 & OD23 & OD13 & OD23 & OD13 & OD23 \\
\hline
2.00 & 2.8817 & 2.9632 & 2.5815 & 2.7162 & 0.28016 & 0.22696 & 1.8665 \\
1.75 & 2.8618 & 2.9245 & 2.5691 & 2.6592 & 0.27263 & 0.24531 & 1.8668 \\
1.50 & 2.8400 & 2.8941 & 2.5648 & 2.6247 & 0.2552 & 0.24945 & 1.8674 \\
1.25 & 2.8118 & 2.8647 & 2.5430 & 2.5956 & 0.24881 & 0.24913 & 1.8681 \\
1.00 & 2.7978 & 2.8439 & 2.5517 & 2.5920 & 0.22612 & 0.23189 & 1.8687 \\
0.75 & 2.7679 & 2.8191 & 2.5362 & 2.5776 & 0.21175 & 0.22143 & 1.8697 \\
0.50 & 2.7386 & 2.8043 & 2.5450 & 2.5815 & 0.19361 & 0.20280 & 1.8702 \\
0.25 & 2.7424 & 2.7885 & 2.5370 & 2.5775 & 0.18539 & 0.19095 & 1.8711 \\
\hline
\end{tabular}
\end{table}
With the introduction of an endogenetic market penetration model in this paper, Figure 3 depicts a decease of total network costs (from ¥9471.2 to ¥9236) and a simultaneous increase of the market penetration (from 20.8% to 21.6%) resulted from LOS improvement of ATIS. Together with results in Table 3, it can be concluded that improvement of ATIS service draws more consumers by providing them punctual arrivals with less travel disutility and therefore the total network costs are cut down.

Moreover, impacts of ATIS on the demand splits in the proposed multimodal network are studied and shown in Table 4 and Figure 4. It can be seen that users with ATIS turns out significant preference for auto mode with rise of LOS of ATIS, and of which less than 10% are left with other two mode types. Meanwhile, the demand splits of unequipped users remain in a steady state of about 65% by walk-metro mode, around 20% by P&R mode and less than 15% by auto mode.

As stated above, it can be easily derived that there is less uncertainty of walk-metro mode and P&R mode on metro sub-network. So that, it is not difficult to understand that equipped users benefit relative less than unequipped users without additional payment for ATIS service. On the other hand, users without ATIS are faced with more uncertainty costs on auto sub-network which push them to metro related mode for travel reliability.

Figure 4 shows that the gulf between demand splits is exacerbated by improvement of ATIS. On the whole, share ratio of auto mode becomes higher at the cost of demand loss on other two modes under rise of LOS. It can be also observed a less range of variation of P&R’s share ratio. Our analysis concludes that is because of the upgrade of PGS to some extent counteract RGS by drawing flows into P&R mode from auto mode.

### Tab. 4. The demand splits among three modes resulted from ATIS

<table>
<thead>
<tr>
<th>LOS of ATIS</th>
<th>User class</th>
<th>OD13(100%in total)</th>
<th>OD23(100%in total)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Mode a</td>
<td>Mode b</td>
</tr>
<tr>
<td>2.00</td>
<td>1</td>
<td>89.15</td>
<td>1.63</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>10.76</td>
<td>69.07</td>
</tr>
<tr>
<td>1.75</td>
<td>1</td>
<td>94.80</td>
<td>0.30</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>10.98</td>
<td>67.12</td>
</tr>
<tr>
<td>1.50</td>
<td>1</td>
<td>91.56</td>
<td>0.71</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>10.59</td>
<td>69.07</td>
</tr>
<tr>
<td>1.25</td>
<td>1</td>
<td>97.36</td>
<td>0.17</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>9.24</td>
<td>68.11</td>
</tr>
<tr>
<td>1.00</td>
<td>1</td>
<td>96.91</td>
<td>0.15</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>11.22</td>
<td>67.33</td>
</tr>
<tr>
<td>0.75</td>
<td>1</td>
<td>98.45</td>
<td>0.09</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>10.54</td>
<td>67.03</td>
</tr>
<tr>
<td>0.50</td>
<td>1</td>
<td>98.27</td>
<td>0.09</td>
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<tr>
<td></td>
<td>2</td>
<td>11.74</td>
<td>66.51</td>
</tr>
<tr>
<td>0.25</td>
<td>1</td>
<td>99.23</td>
<td>0.06</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>11.69</td>
<td>66.52</td>
</tr>
</tbody>
</table>

![Fig. 3. Impacts of ATIS on market penetration](image)

![Fig. 4. Impacts of ATIS on demand splits](image)

**CONCLUSIONS**

In this paper, we present a multiclass multimodal probit-based traffic equilibrium model under ATIS where commuters are discretized into two classes, those equipped and unequipped with ATIS. Both of user classes would make their travel choice decisions following probit-based SUE principle. LOS of ATIS is considered
explicitly to catch impacts on travelers' behaviors, such as mode choice, route choice, parking choice. In the proposed multimodal network, there are three type of mode, auto mode, walk-metro mode or P&R mode and two kind of parking facilities, parking lot and P&R site. Additionally, an endogenous market penetration is introduced to make the proposed model more close to reality. The SUE conditions is formulated as a VI problem and solved by a heuristic algorithm based on Monte Carlo and MSA.

The numeric results show (1) users equipped with ATIS prefer travelling by auto on auto sub-network which is of more uncertainty; (2) Unequipped users chase trip reliability by choosing metro related mode; (3) Parking facilities with high LOS draw considerable users equipped with ATIS who exclude unequipped users; (4) Improvement of ATIS brings decrease of equipped users’ travel disutility, addition of benefits and accordingly more consumers are attracted leading to a rise of the market penetration; (5) As for P&R mode, there exist counteractions between RGS and PGS on demand splits between auto and P&R; (6) Impacts of ATIS on unequipped users are indistinctive and as a result, only auto share ratio rises with upgrade of ATIS on the multimodal network.

References