

A two-stage policy for improving the efficiency of the traffic network by providing value-added ATIS service

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Abstract. Based on the pay-per-use charge in mobile Apps, value-added advanced traveler information systems (VATIS) service can be provided in traffic networks. From the perspective of the traffic manager, we propose a two-stage policy for improving the efficiency of traffic networks by providing VATIS service. At the first stage, the traffic manager selects several ATIS service providers, then offers seed fund to each of them to encourage VATIS service provision. At the second stage, the traffic manager announces a given target of the total market penetration of VATIS service and encourages service providers to achieve it together. If they could complete the task, compensation will be paid. To evaluate the efficiency of this policy, four scenarios are formulated by four bi-level models, and the total travel time is set as the evaluation indicator. Numerical experiments show that, the suggested policy can reduce total travel time dramatically if the market penetration target has been appropriately selected.

1 Introduction

In previous years, people used to make their travel decisions with the aid of vehicle navigation systems, which are the predecessor of Advanced Traveler Information System (ATIS). At that time, ATIS service providers can sell navigators and charge for map updating services to gain profit. However, due to the severe competition in the ATIS market, nowadays almost all ATIS service providers (e.g., Goggle Map or Amap) offer the basic route guidance service for free. In this case, they begin to seek for profit by providing the value-added ATIS (VATIS) service based on the evidence that people are willing to pay to the save travel time [1-5]. As an actual example, Amap offers several kinds of value-added services to travelers, such as taxi service, hotel reservation, and online coupons obtaining, which are bringing Amap a tidy profit. Consequently, ATIS service providers are dedicated to maximize their market scales in this new era. That can also contribute to enhancing the efficiency of the traffic networks [6]. But the expensive operating cost for collecting traffic information is the major limitation for ATIS service providers [7], especially when the information quality is required to be as accurate as possible. Thus, policies for supporting ATIS service providers, mainly by finance support, need to be issued.

In this study, we suggest a two-stage policy from the perspective of the traffic manager. At the first stage, the traffic manager selects several ATIS service providers, and offers seed funds to each of them. Considering that ATIS services of different service providers are

coessential products, service providers will cooperate with each other after severe competition, then act as a community to maximize their profits. Then the policy should move to the second stage. The traffic manager announces a given target of the total market penetration of VATIS services and asks service providers to achieve it together. If they could complete the target, reasonable compensations will be paid to them.

If the traffic manager compensates service providers directly during the period of market competition and asks them to achieve fixed targets of the market penetration of VATIS services, it might be a tough work to decide which values of fixed targets should be set for each service providers, and how much compensates should be given. By dividing this policy into two stages, the policy can make full use of the market competition in the first stage, because the traffic manager can get a clear understanding of each service provider, so that both compensations and the fixed target of the total market penetration of VATIS services can be made more wisely and efficiently. Besides, compensations will be given to the community of service providers, this approach can avoid the trouble of setting sub-targets for every selected service provider.

We illustrate the evolution of traffic state of the traffic network where the two-stage policy implemented, by four cases, namely the basic case, the competition case, the cooperation case, and the restricted case. The basic case describes the initial state of the traffic network where only the basic ATIS service is provided, and it will be treated as the comparative standard of other three cases. The competition case and the cooperation case are used to depict market behaviour of VATIS service providers in

the first stage. The restricted case presents the state of the traffic network in the second stage. Then, four models are proposed to formulate these cases, respectively. At last, the efficiency of the suggested policy is tested by the total travel time based on a traffic survey which is carried out in Hongkou district of Shanghai, China.

The study is structured as follows. In section 2, four models are developed for demonstrating the states of the traffic network after implemented the two-stage policy. Numerical analyses are given in Section 3 based on a traffic survey. Section 4 concludes this study.

2 Modeling

2.1 Basic case: the initial state of the traffic network

Consider a traffic network $\mathbf{G}=(\mathbf{N},\mathbf{A})$ which has \mathbf{N} nodes and \mathbf{A} links, its origin-destination (OD) matrices are given and fixed, and d^{rs} (the set \mathbf{d}) denotes the total travel demand from origin $r \in \mathbf{R}$ to destination $s \in \mathbf{S}$. We assume that the basic ATIS service is provided for free, so there is no need to consider about their profit. Denote the basic ATIS service quality as θ_0 , then it can be used as the parameter of the Logit-based traffic assignment in the network. Therefore, the link flow pattern can be formulated by the following mathematical program:

$$\begin{aligned} \min FB(\mathbf{f}) = & \sum_{a \in \mathbf{A}} \int_0^{v_a} t_a(x) dx \\ \text{[Model-1]} \quad & + \sum_{r \in \mathbf{R}} \sum_{s \in \mathbf{S}} \sum_{j \in \mathbf{J}_{rs}} f_j^{rs} \frac{1}{\theta_0} \ln f_j^{rs} \end{aligned} \quad (1)$$

subject to

$$\sum_{j \in \mathbf{J}_{rs}} f_j^{rs} = d^{rs} \quad \forall r \in \mathbf{R}, s \in \mathbf{S}, \quad (2)$$

$$v_a = \sum_{r \in \mathbf{R}} \sum_{s \in \mathbf{S}} \sum_{j \in \mathbf{J}_{rs}} f_j^{rs} \delta_{aj}^{rs} \quad \forall a \in \mathbf{A}, \quad (3)$$

$$f_j^{rs} \geq 0 \quad \forall r \in \mathbf{R}, s \in \mathbf{S}, j \in \mathbf{J}_{rs}. \quad (4)$$

In Model-1, j (the path set \mathbf{J}_{rs}) is the index of path in OD pair rs , f_j^{rs} is the flow of path j in OD pair rs . v_a (the link flow set \mathbf{v}) represents the flow in link a . $t_a(v_a)$ is the link travel time function of link a . δ_{aj}^{rs} equals 1 if path j in OD pair rs uses the link a , and δ_{aj}^{rs} equals 0 otherwise.

Solving Model-1, the initial equilibrium state of the traffic network can be obtained and defined as

$$\mathbf{f}^0 := \{\mathbf{f} \in \arg \min FB(\mathbf{f})\}. \quad (5)$$

2.2 Models for evaluating the efficiency of the two-stage policy

As we have mentioned in the introduction, the state of the traffic network after implemented the two-stage policy can be described by four cases: the basic case, the competition case, the cooperation case, and the restricted case. In this subsection, they are modeled in mathematical forms based on the bi-level models. In the lower-levels of these models, stochastic equilibrium

theories will be applied to describe the equilibrium state of the traffic network. At the same time, the upper-levels of these models are formulated by profit functions of VATIS service providers. We will present the common lower-level model at first, and then give the upper-level models of three bi-level models one after another.

2.2.1 The mixed stochastic equilibrium state of the traffic network

Suppose that there has M VATIS service providers in the traffic network, and the set of VATIS service providers is denoted by $\mathbf{M} = \{m : 1, 2, 3, \dots, M\}$. Let $m=0$ be the initial class of travelers who only use the basic ATIS service for free, and $m \in \mathbf{M}$ be the class of travelers who use the service of VATIS service provider m and pay for the service. Therefore, the whole set of travelers in the traffic network can be expressed as $\mathbf{M}_0 = \mathbf{M} \cup \{0\} = \{m : 0, 1, 2, 3, \dots, M\}$ where m is the index of both VATIS service providers and the classes of travelers. d_m^{rs} denotes the demand of the m th class of travelers. Under assumptions of homogeneous travelers, principles of stochastic user equilibrium (SUE) [8], the mixed stochastic equilibrium model can be formulated as below:

$$\begin{aligned} \min_{\mathbf{f}, \mathbf{d}} F(\mathbf{f}, \mathbf{d}, \boldsymbol{\theta}, \boldsymbol{\tau}) = & \sum_{a \in \mathbf{A}} \int_0^{v_a} t_a(x) dx \\ \text{[Model-} & + \sum_{r \in \mathbf{R}} \sum_{s \in \mathbf{S}} \sum_{m \in \mathbf{M}_0} \sum_{j \in \mathbf{J}_{rs}} f_{mj}^{rs} \left(\tau_m^{rs} + \frac{1}{\theta_m} \ln f_{mj}^{rs} \right) \end{aligned} \quad (6)$$

subject to

$$\sum_{j \in \mathbf{J}_{rs}} f_{mj}^{rs} = d_m^{rs} \quad \forall r \in \mathbf{R}, s \in \mathbf{S}, m \in \mathbf{M}_0, \quad (7)$$

$$\sum_{m \in \mathbf{M}_0} d_m^{rs} = d^{rs} \quad \forall r \in \mathbf{R}, s \in \mathbf{S}, \quad (8)$$

$$f_{mj}^{rs} \geq 0 \quad \forall r \in \mathbf{R}, s \in \mathbf{S}, m \in \mathbf{M}_0, j \in \mathbf{J}_{rs}, \quad (9)$$

$$v_a = \sum_{r \in \mathbf{R}} \sum_{s \in \mathbf{S}} \sum_{m \in \mathbf{M}_0} \sum_{j \in \mathbf{J}_{rs}} f_{mj}^{rs} \delta_{aj}^{rs} \quad \forall a \in \mathbf{A}, \quad (10)$$

$$\tilde{c}_{mj}^{rs} = \eta \sum_{a \in \mathbf{A}} t_a(v_a) \delta_{aj}^{rs} + \tau_m^{rs} \quad \forall r \in \mathbf{R}, s \in \mathbf{S}, m \in \mathbf{M}_0, j \in \mathbf{J}_{rs} \quad (11)$$

$$P_{mj}^{rs} = \frac{\exp(-\theta_m \tilde{c}_{mj}^{rs})}{\sum_{k \in \mathbf{J}_{rs}} \exp(-\theta_m \tilde{c}_{mk}^{rs})} \quad \forall r \in \mathbf{R}, s \in \mathbf{S}, m \in \mathbf{M}_0, j \in \mathbf{J}_{rs}, \quad (12)$$

$$c_m^{rs} = \sum_{j \in \mathbf{J}_{rs}} P_{mj}^{rs} \tilde{c}_{mj}^{rs} \quad \forall r \in \mathbf{R}, s \in \mathbf{S}, m \in \mathbf{M}_0, \quad (13)$$

$$Q_m^{rs} = \frac{\exp(-\varphi c_m^{rs})}{\sum_{k \in \mathbf{M}} \exp(-\varphi c_k^{rs}) + \exp(-\alpha - \varphi c_0^{rs})} \quad \forall r \in \mathbf{R}, s \in \mathbf{S}, m \in \mathbf{M} \quad (14)$$

$$Q_0^{rs} = 1 - \sum_{m \in \mathbf{M}} Q_m^{rs} \quad \forall r \in \mathbf{R}, s \in \mathbf{S}, \quad (15)$$

$$\bar{d}_m^{rs} = d^{rs} Q_m^{rs} \quad \forall r \in \mathbf{R}, s \in \mathbf{S}, m \in \mathbf{M}_0. \quad (16)$$

In (6)-(16), variables and parameters are defined as below. f_m^{rs} (the path flow set \mathbf{f}) denotes the flow of path j in the m th class of travelers in OD pair rs . τ_m^{rs} is the service price of the m th VATIS service provider in OD pair rs , and $\tau_0^{rs} = 0$ for all OD pair rs . θ_0 is the service quality of the basic ATIS service, θ_m is the service quality of the m th VATIS service provider, and there has $\theta_m > \theta_0$ for all $m \in \mathbf{M}$. \tilde{c}_m^{rs} is the travel cost of a traveler of the m th class when he chooses path j in OD pair rs . η is a positive parameter for transferring travel times into monetary value. P_{mj}^{rs} is the probability of a traveler of the m th class for choosing path j in OD pair rs . c_m^{rs} is the average travel cost of travelers of the m th class. Q_m^{rs} is the probability of a traveler for choosing the service of the m th VATIS service provider in OD pair rs , and Q_0^{rs} is the probability of a traveler for choosing the basic ATIS service in OD pair rs . The choosing process (14)-(15) is formulated in the similar way to Yang [9] has did, φ and α are parameters in it.

2.2.2 Competition case in the first stage

At the first stage of the suggested two-stage policy, VATIS service providers will compete by altering their service strategies, including alter service prices and service qualities of themselves to maximize their profits. Denote Ω_m as the profit of the m th VATIS provider, its pricing strategy as $\mathbf{x}_m = (\theta_m, \tau_m^{rs})$, and the group pricing strategy as $\mathbf{z} = (\theta_0, \tau_0^{rs}, \theta_1, \tau_1^{rs}, \dots, \theta_M, \tau_M^{rs})$. The bi-level model for describing competition scenario can be formulated as below:

$$\begin{aligned} \text{[Model-2]} \quad & \max_{\mathbf{x}_m} \Omega_m(\mathbf{d}, \mathbf{x}_m) \\ & = \sum_{r \in \mathbf{R}} \sum_{s \in \mathbf{S}} \tau_m^{rs} d_m^{rs} - \sum_{i \in I} \phi_{im} \theta_m^i \quad \forall m \in \mathbf{M}, \end{aligned} \quad (17)$$

subject to

$$\mathbf{d} \in \arg \min_{\mathbf{f}, \mathbf{d}} \mathbf{F}(\mathbf{f}, \mathbf{d}, \mathbf{z}), \quad (18)$$

$$\theta_m \geq 0, \quad \tau_m^{rs} \geq 0 \quad \forall r \in \mathbf{R}, s \in \mathbf{S}, m \in \mathbf{M}. \quad (19)$$

In equation (17), the first term is the total revenue of the m th VATIS service provider, the second term is the total operation cost of the m th VATIS service provider, ϕ_{im} is the cost coefficient of the cost related to the information quality and $\mathbf{I} = \{i : i \in R^+ \setminus [0,1]\}$. We construct the operation cost function in the exponential form under the consideration of arguments of related literatures on ATIS service pricing [10-12].

It should be noted that the service quality and the service price are two sets of decision variables in the upper-level model of Model-2. If we simplify the competition case into a process of sequential decision making, the competition among VATIS service providers would turn out to be a Nash game [13]. The reaction method in game theory can be applied in analyzing the optimal solution of Model-2. Obtain the first order partial

derivatives of Ω_m with respect to θ_m and τ_m^{rs} , and let them equal to 0, we can obtain the optimal decision of the m th VATIS service provider:

$$\begin{cases} \frac{\partial \Omega_m(\mathbf{d}, \mathbf{x}_m)}{\partial \theta_m} = 0 & \forall m \in \mathbf{M} \\ \frac{\partial \Omega_m(\mathbf{d}, \mathbf{x}_m)}{\partial \tau_m^{rs}} = 0 & \forall r \in \mathbf{R}, s \in \mathbf{S}, m \in \mathbf{M} \end{cases} \quad (20)$$

Define set $\mathbf{K} = \{k : k \in \mathbf{M} \setminus \{m\}\}$, and denote R^1 and R^2 as the implicit reaction functions of θ_m and τ_m^{rs} , respectively. The corresponding reaction functions can be presented as

$$\theta_m = R_{k \in \mathbf{K}}^1(\theta_k, \tau_k^{rs}), \tau_m^{rs} = R_{k \in \mathbf{K}}^2(\theta_k, \tau_k^{rs}) \quad \forall r \in \mathbf{R}, s \in \mathbf{S}, m \in \mathbf{M} \quad (21)$$

The optimal solution should meet

$$\begin{cases} \theta_m^* = R_{k \in \mathbf{K}}^1(\theta_k^*, \tau_k^{rs*}) & \forall m \in \mathbf{M} \\ \tau_m^{rs*} = R_{k \in \mathbf{K}}^2(\theta_k^*, \tau_k^{rs*}) & \forall r \in \mathbf{R}, s \in \mathbf{S}, m \in \mathbf{M} \end{cases} \quad (22)$$

Solving Model-2, we have its optimal solution:

$$\mathbf{f}^* := \{\mathbf{f} \in \arg \max_{\mathbf{x}_m} \Omega_m(\mathbf{d}, \mathbf{z}), \forall m \in \mathbf{M}\}. \quad (23)$$

2.2.3 Cooperation case in the first stage

In most cases, service providers can gain more profit by cooperation, so in the first stage, VATIS service providers will choose cooperation after the drastic market competition. We develop another bi-level model called Model-3 for this case. Denote G as the total profit of M VATIS service providers and $\mathbf{X} := \mathbf{z} \setminus \{(\theta_0, \tau_0^{rs})\}$, then the cooperation scenario can be formulated as below:

$$\begin{aligned} \text{[Model-3]} \quad & \max_{\mathbf{X}} G(\mathbf{d}, \mathbf{X}) = \sum_{m \in \mathbf{M}} \Omega_m \\ & = \sum_{m \in \mathbf{M}} \sum_{r \in \mathbf{R}} \sum_{s \in \mathbf{S}} \tau_m^{rs} d_m^{rs} - \sum_{m \in \mathbf{M}} \sum_{i \in I} \phi_{im} \theta_m^i, \end{aligned} \quad (24)$$

subject to (18)-(19).

Denote the optimal solution of Model-3 as $(\bar{\mathbf{d}}, \bar{\mathbf{X}}) = \arg \max_{\mathbf{X}} G(\mathbf{d}, \mathbf{X})$, where $\bar{\mathbf{d}} = (\bar{d}_1^{rs}, \bar{d}_2^{rs}, \dots, \bar{d}_M^{rs})$, $\bar{\mathbf{X}} = (\bar{\theta}_1, \bar{\tau}_1^{rs}, \bar{\theta}_2, \bar{\tau}_2^{rs}, \dots, \bar{\theta}_M, \bar{\tau}_M^{rs})$, and denote the stable solution of Model-2 as $(\mathbf{d}^*, \mathbf{x}_m^*)$ for all $m \in \mathbf{M}$, we can know that, only if the follow constraint was met, the cooperation would happen:

$$\bar{G}(\bar{\mathbf{d}}, \bar{\mathbf{X}}) > \sum_{m \in \mathbf{M}} \Omega_m^*(\mathbf{d}^*, \mathbf{x}_m^*). \quad (25)$$

Solving Model-3, we have its optimal solution:

$$\bar{\mathbf{f}} := \{\mathbf{f} \in \arg \max_{\mathbf{X}} G(\mathbf{d}, \mathbf{X})\}. \quad (26)$$

2.2.4 Restricted case in the second stage

Cooperation among VATIS service providers may lead to the increasing of the total travel time and other loses of social welfare issues while they pursuing higher profit. The second stage of this policy is aimed at dealing with this problem by restricted measures. The specific approach is, the traffic manager promises to compensate

VATIS service providers, but a given and fixed target of the total market penetration of VATIS service should be achieved. Denote the current total profit of M VATIS services as GR , and denote Q_{fixed} as the fixed target, then the restricted scenario can be formulated as

[Model-4]

$$\begin{aligned} \max_{\mathbf{X}} GR(\mathbf{d}, \mathbf{X}) &= \sum_{m \in \mathbf{M}} \sum_{r \in \mathbf{R}} \sum_{s \in \mathbf{S}} \left(\tau_m^{rs} d_m^{rs} - \sum_{i \in I} \phi_{im} \theta_m^i \right) \\ &- N \cdot \max \left\{ 0, Q_{fixed} - \sum_{m \in \mathbf{M}} \sum_{r \in \mathbf{R}} \sum_{s \in \mathbf{S}} w^{rs} Q_m^{rs} \right\} \end{aligned} \quad (27)$$

subject to (18) - (19). In (27), the first term is the summation of profit functions of all VATIS service providers, and the second term is a penalty (opportunity cost) for not achieving the fixed market penetration target Q_{fixed} of VATIS service in the given highway network.

N is a very large number, and $w^{rs} = \frac{d^{rs}}{\sum_{r \in \mathbf{R}} \sum_{s \in \mathbf{S}} d^{rs}}, \forall r \in \mathbf{R}, s \in \mathbf{S}$.

Consider a fixed market penetration target Q_{fixed} of VATIS services in the traffic work, denote the optimal solution set of VATIS service providers as $(\hat{\mathbf{d}}, \hat{\mathbf{X}}) = \arg \max_{\mathbf{X}} GR(\mathbf{d}, \mathbf{X})$. Denote the total compensation as β , then the lower bound of β will be determined by

$$\beta \geq \max \left\{ 0, G(\bar{\mathbf{d}}, \bar{\mathbf{X}}) - GR(\hat{\mathbf{d}}, \hat{\mathbf{X}}) \right\}. \quad (28)$$

Solving Model-4, we obtain its solution:

$$\hat{\mathbf{f}} := \left\{ \mathbf{f} \in \arg \max_{\mathbf{X}} GR(\mathbf{d}, \mathbf{X}) \right\}. \quad (29)$$

2.3 The evaluation indicator and solving method

The total travel time has been extensively used as the indicator in evaluating the efficiency of traffic networks both in studies and practices, it can be calculated by

[Indicator]

$$T(\mathbf{f}) = \sum_{r \in \mathbf{R}} \sum_{s \in \mathbf{S}} \sum_{j \in \mathbf{J}_n} f_j^{rs} \left[\sum_{a \in \mathbf{A}} t_a(v_a) \delta_{aj}^{rs} \right], \quad (30)$$

where

$$v_a = \sum_{r \in \mathbf{R}} \sum_{s \in \mathbf{S}} \sum_{j \in \mathbf{J}_n} f_j^{rs} \delta_{aj}^{rs} \quad \forall a \in \mathbf{A}. \quad (31)$$

If the implement of the suggested two-stage policy could improve the efficiency of the traffic network, $T(\mathbf{f}^*)$, $T(\bar{\mathbf{f}})$ and $T(\hat{\mathbf{f}})$ will all be smaller than $T(\mathbf{f}^0)$. Numerical experiments are also presented to demonstrate this argument.

To solve these models, the method of successive averages (MSA) and particle swarm optimization (PSO) are tested and used in this study. MSA is used to solve the lower-levels of bi-level models and Model-1. PSO is used in solving the upper-level models of all the bi-level models. Besides, the detail steps of MSA and its extensions are elaborated in Yang [9]. PSO also is a well-developed method which has been provided in many kinds of mathematical programming software [14]. Thusly, we can use these methods directly.

3 Numerical experiments

3.1 Data employed and parameter settings

The traffic survey was carried out during the evening rush hours (from 3:30 pm-7:30 pm) from August 9th to August 19th, 2016 (only weekdays) in Hongkou district of Shanghai, China. As shown in Figure 1, Figure 2 and Table 1, 30 main roads of Hongkou district are inspected. Figure 1 is the spatial distribution map of Hongkou district, and Figure 2 is the structure sketch of the road network in Hongkou district.



Figure 1. Map of Hongkou

Table 1. Survey results of Hongkou district

Node A	Node B	AB flows	BA flows	C_a	t_a^0
1	4	2490	2638	2069	3
2	5	3764	3454	2652	3
3	4	3876	3170	2621	1
4	5	--	--	4118	2
4	11	--	--	1034	1
5	6	3706	3704	1211	1
5	8	2446	2624	796	1
7	5	--	--	849	1
7	8	--	--	647	1
8	9	1776	1926	636	1
8	13	2680	2582	796	1
10	11	--	--	1248	1
11	12	3856	3904	1622	1
12	13	2650	2924	1273	1
12	7	2958	2584	1273	1
12	16	1582	1966	1379	1
13	14	1748	2120	2334	2
13	17	1980	2286	1008	1
15	16	--	--	1061	1
16	18	1265	1375	1591	2
17	19	2997	2991	1662	1
17	14	3391	3101	1248	1
18	21	2896	2612	624	1

18	19	2825	2690	1662	1
19	22	552	639	451	1
20	21	3548	3958	998	1
21	22	3076	3110	1036	1
21	24	--	--	1186	1
22	23	3010	2990	1747	1
22	25	--	--	1167	1

Unit: persons/hour is the unit of C_a , minutes is the unit of t_a^0 .

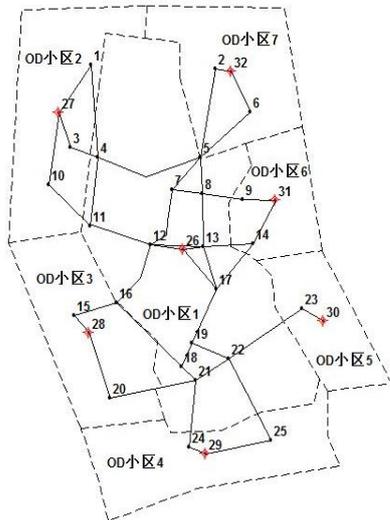


Figure 2. Structure of Hongkou

Figure 2 is created in TransCAD and intersections are labeled as node 1 to node 25. At the same time, 26 to 32 are centroids of traffic zones corresponding to OD zone 1 to OD zone 7. Note that 26 to 32 are virtual nodes in this map but they are necessary for OD estimation, so we assume that every link connects with these centroids have the capacity of 10000 persons/hour and free flow travel time of 0 minute. The SUE method has been used in OD estimation for 20 iterations, and the default convergence value is 0.01. Two parameters of BPR function are set as 0.15 and 4, respectively. Finally, we have obtained the matrix of OD travel demands of Hongkou district, as shown in Table 2.

Table 2. Results of OD estimation in TransCAD (unit: persons/hour)

OD zone	1	2	3	4	5	6	7
1	0	790	67	19	21	3316	2778
2	531	0	161	40	38	1012	2252
3	140	311	0	321	1538	487	967
4	97	148	3684	0	651	197	428
5	69	111	2610	398	0	132	273
6	1413	1385	245	49	45	0	3166
7	4469	2812	1020	243	158	2369	0

To simplify the computation process of our numerical experiments, we only select two OD pairs from the network in which freeways are included. Two selected OD pairs are $OD(1,7)$ and $OD(2,7)$. Their travel demands

are $OD(1,7) = 2779$ (persons/hour) and $OD(2,7) = 2253$ (persons/hour), which have been estimated in Table 2.

In our numerical experiments, other parameters are set as below. θ_0 is 0.1, BPR function is $t_a = t_a^0 \left[1 + 0.15 \left(\frac{V_a}{C_a} \right)^4 \right]$, $\alpha = 1.75$, $\varphi = 0.35$, $\eta = 1$. There are two VATIS service providers in this numerical network, so $M = 2$. their parameters of profit functions: $\phi_{11} = 400$, $\phi_{12} = 1000$, $\phi_{21} = 500$, $\phi_{22} = 1200$ and $i = 2$. The boundaries of decision variables are $\bar{\mathbf{X}} = \left\{ \begin{array}{l} \mathbf{X}_m = (\theta_m, \tau_m^{rs}) : 0.1 \leq \theta_m \leq 1.0, 0 \leq \tau_m^{rs} \leq 10, \\ \forall m \in \{1, 2\}, r \in \{1, 2\}, s \in \{7\} \end{array} \right\}$.

3.2 Optimal solutions of the four cases

Table 3 depicts optimal solutions of the four cases. Look through each stage of the suggested policy, we can find that, the result of the restricted scenario is the best which has the lowest total travel cost. It indicates that setting up the market penetration target of VATIS services is an effective way to decrease the total travel time if VATIS service providers are motivated to achieve the target.

Table 3. Optimal solutions of four cases

Cases	$(\theta_1, \theta_2, \tau_1^{17}, \tau_2^{17}, \tau_1^{27}, \tau_2^{27}, \Omega \setminus G \setminus GR, T(f))$
Basic	(0.1, 0.1, 0, 0, 0, 0, —, 84865)
Competition	(0.56, 0.52, 4.13, 4.05, 4.39, 4.32, 7671, 58652)
Cooperation	(0.57, 0.53, 6.35, 6.28, 6.73, 6.70, 8851, 64953)
Restricted	(0.53, 0.48, 1.48, 1.15, 4.10, 3.93, 5728, 57047)

Unit: θ_i has no unit, yuan/per time is the unit of τ_i^{rs} , yuan is the unit of $\Omega \setminus G \setminus GR$ and $T(f)$.

3.3 Find the suitable fixed market penetration target of VATIS service

To find the most suitable fixed market penetration target of VATIS services in the traffic network, an analysis on the fixed market penetration target of VATIS services has been conducted. The fixed market penetration target Q_{fixed} changes from 0.1 to 0.9 and each step is 0.05. The setting of other parameters is the same as that of Section 3.2 apart from Q_{fixed} .

Note that Q_{fixed} is no more than a fixed target for VATIS service providers, so if Q_{fixed} was too high, service providers might not be able to attain it. Thus, we need to check the realized market penetration $Q_{actually}$ to find a suitable value of Q_{fixed} . Figure 3 illustrates the values of $Q_{actually}$ in the numerical network under varied levels of Q_{fixed} . We can see that $Q_{actually}$ will be lower than Q_{fixed} , if Q_{fixed} was set too high. Reasons are twofold. On

the one hand, if Q_{fixed} was easy to achieve, so the traffic manager should choose Q_{fixed} properly and reasonably.

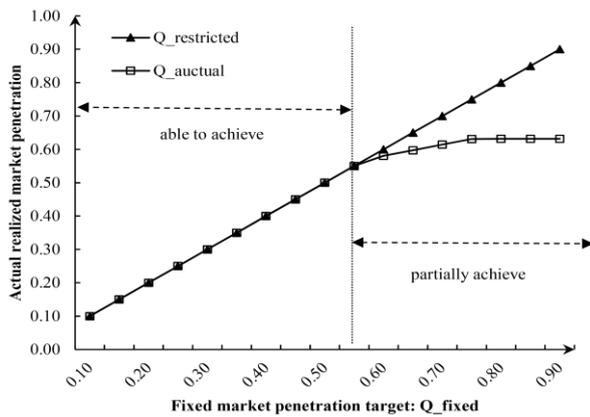


Figure 3. The differences between fixed market penetration target and realized market

Besides, $Q_{actually}$ has a tendency to increase to a stable value ($Q_{actually} = 0.63$ when $Q_{fixed} \geq 0.80$, as shown in Figure 3), that is the reasonable value of Q_{fixed} for pushing VATIS service providers spare no effort in decreasing the total travel time. At the same time, the saving time will be $\Delta T' = 18404$ (minutes) (28.33% improvement), and the total saving time will be $\Delta T = 38316$ (minutes) (45.15% improvement), when compared with the total travel time in the basic scenario. Moreover, the total compensation needs to be no less than $\Delta\beta = G(\bar{\mathbf{d}}, \bar{\mathbf{z}}) - GR(\hat{\mathbf{d}}, \hat{\mathbf{z}}) = 10811$ (yuan).

In summary, we find that there has a stable value of the fixed market penetration Q_{fixed} , in our experiments, it equals 0.80, where the biggest effectiveness of reducing the total travel time of the network can be attained. At the same time, a total compensation $\beta \geq \Delta\beta$ (in our experiments, β should be larger than 10811 yuan) also needs to be guaranteed, with the aim of motivating VATIS service providers to do their best in improving the efficiency of the traffic network.

4 Conclusion

In this study, a two-stage policy aiming at improving the efficiency of the traffic network is proposed based on the feasibility of charging value-added ATIS services. Models of describing each case in this policy are formulated and the evaluation indicators are pointed out. Numerical results show that the suggested policy can decrease the total travel time substantially.

The proposed two-stage policy can be very helpful to the traffic manager in regulating the behavior of ATIS service providers, especially when they are competing for ATIS market shares. However, this study also has limitations. It only has discussed about competition and cooperation among ATIS service providers by considering pricing strategy and the information quality they provided. Other potential factors, such as the

influence of word-of-mouth, preferences of travelers, also need to be discussed in the future study.

Further extensions of this study can be investigated as below. Constitutes of the profit function of VATIS service providers would be an important issue in analyzing the effectiveness of this policy. Investigating its constituent part can enhance the veracity and rationality of the suggested policies. Besides, the evaluation criteria of target completion in the second stage of the suggested policy are interesting extension, hierarchic criteria might be the proper way of the evaluation of the suggested policy. Moreover, the suitable total compensation paid by the traffic manager needs to be further discussed.

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