Modeling Traveler's Day-to-day Departure Time Choice with Social Network Information: A Bayesian Belief Approach

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Abstract

Benefit from the prevalence of social network applications in recent years, people could share information with friends very conveniently. Meanwhile, the widely use of mobile devices, such as mobile phone and car GPS, helps people get their current locations promptly. Combining social networks and location-aware devices, travelers could share their travel experience and location information to friends, and get other's information in return. This becomes a new type of information about traffic conditions, generated by travelers themselves and transmitted through social networks. Compared with traditional traffic information, this information has many unique properties: up-to-date, user specific and multi-source (travelers may receive information from several friends at once time). So a natural question arises: Can we exploit the shared traffic information in social networks to help tailor the travel plans for users? This problem is drawing increasing attention from researchers. Existing studies on this topic could be categorized into two folds according to the activities of their concerns: one is traveler's own decision making, and the other is their social activities. When planning their own trips, travelers may be affected by the advices or feedbacks from friends on destinations (Han et al., 2011; Iryo et al., 2012; Kowald and Axhausen, 2012). Besides, people could get to know new friends and negotiate the time and location of their social activities by using social networks (Ronald et al., 2012; van den Berg et al., 2013). In these related works, most of them focus on non-work travel activities, such as sightseeing and shopping, which are flexible in trip-making. In this study, we consider a more frequent and time-constrained travel behavior, namely, commuting, and focus on people's daily departure time choice, with the influence of social networks.

Departure time choice is an important component of commuters' daily travel plan and its outcome will be reflected in the traffic flow and has direct effect on congestion. Understanding and modeling commuters' departure time choices is an important problem in transportation research (Jou et al., 2008). When making decisions, travelers not only learn from their own experience, but also from external traffic information (e.g. ATIS, online map, apps for mobile phones) to adjust their departure times dynamically. In this study, we target to understand

whether the information from social network would have significant influence on travelers' day-to-day departure time choices, how they deal with this multi-source information in their decision, and its influence on the performance of the transportation network.

We model the learning process of travelers by using a Bayesian belief updating approach. Bayesian learning is a method widely used in transportation to describe travelers' decision and learning process from information under uncertainty, such as route choice (Chen and Mahmassani, 2004; Chorus et al., 2009; Parvaneh et al., 2012). In this study, we consider the case of a new commuter corridor, where travelers need to go through every day from home to work with the same work start time. The free flow travel time of the corridor is known, while the capacity is variable from day to day. Let *D* denote the set of all latent departure times, and *T* denote the set of perceived possible travel times. Both departure time and perceived travel time are modeled to be discrete time intervals for simplicity with $|D|=m$ and $|T|=n$. At the beginning, we consider that travelers have prior knowledge about the corridor based on their previous travel experience. Specifically, for each departure time $d_k \in D \ (k=1,2,\cdots,m)$, traveler *i*'s perception of travel time $t_j \in T \ (j=1,2,\cdots,n)$ is denoted by $\Pr(t_j)$, and the expected utility (*EU*) of d_k is calculated as Equation (1), where $f(d_k,t_j)$ is the travel cost associated with departure time d_k and arrival time t_j.

$$EU(d_k) = -\sum_{j=1}^{n} \Pr(t_j)\cdot f(d_k,t_j) \tag{1}$$

The traveler will choose the departure time with the maximum *EU* on his first day. Once traveler *i* has gained travel experience of this corridor, he will update his perception about the travel time of the corresponding departure time d_k based on the Bayes rule:

$$\Pr(t\mid t^e) = \frac{\Pr(t^e\mid t)\cdot \Pr(t)}{\sum_{j=1}^{n}\Pr(t^e\mid t_j)\cdot \Pr(t_j)} \tag{2}$$

where t^e is the experienced travel time and

$$\Pr(t^e\mid t) = \begin{cases} p^e & \text{if } t^e = t \\ (1-p^e)/(n-1) & \text{otherwise} \end{cases} \qquad p^e \in [0,1] \tag{3}$$

Here, p^e can be considered as the belief of traveler *i* on the consistency of the traffic conditions between this day and the next day. Similarly, if the traveler received the travel records (e.g. travel time, arrival time, cost) from friends who shared the same route as his from the social network, he will update the perceived travel time for these departure time points chosen by his friends as well. For each friend s belonging to individual *i*'s set of friends S_i, with the experienced departure time d^s and travel time t^s, the updated perceived travel time of traveler *i* on departure time d^s is:

$$\Pr(t \mid t^s) = \frac{\Pr(t^s \mid t) \cdot \Pr(t)}{\sum_{j=1}^{n} \Pr(t^s \mid t_j) \cdot \Pr(t_j)} \quad (4)$$

and

$$\Pr(t^s \mid t) = \begin{cases} p^s & \text{if} \quad t^s = t \\ (1-p^s)/(n-1) & \text{otherwise} \end{cases} \qquad p^s \in [0,1] \quad (5)$$

where p^s is the belief of traveler *i* to the information provided by friend *s*. It is the combination of the credibility of this friend and p^e that will modify the traveler's subsequent departure time. The amount of friends is determined by the social network setting and configuration. The frequency of updating on one day given friends' information is affected by the number of connected friends, the information spread speed, and the diversity of their departure time choices. Based on the updated perception of travel time, travelers recalculated the expected utility for these departure time points, and choose the best one from *D*. The updating process will be repeated from day to day, to decide the departure time on the next day.

Based on the proposed learning model, we test the performance of this traffic corridor with the influence of social network information by using Monte Carlo simulations. In this study, we assume that all the information reported by friends is accurate, i.e. $p^e = p^s = p$, which will be treated as the same as travelers' own experience. *N* agents are simulated as commuters traveling through the corridor, with randomly generated initial perception of travel time on all feasible departure time points. Different social network configurations are generated to connect travelers, with such connections maintained throughout the simulation. Specifically, the expected utility is calculated as the following; the higher the travel cost is, the lower the utility would be.

$$EU(d_k) = -\sum_{j=1}^{n} \Pr(t_j) \cdot [\alpha t_j + \beta \cdot sde(d_k, t_j) + \gamma \cdot sdl(d_k, t_j)] \quad (6)$$

where $sde(d_k, t_j)$ and $sdl(d_k, t_j)$ are the schedule delay early and late, respectively, and α is the unit time cost of traveling on road; β and γ are the unit time cost of being early and late, respectively. The values of α, β, γ are set to be 0.5, 0.3, 1.2, respectively, in the simulation. Each agent updates the perceived travel time according to his experience and friends' experience (if any) on each day and makes the decision for the next day. Under this framework, we select three kinds of social network structure, namely, random walk, small-world, and scale free, and four levels of information coverage rate, 0%, 40%, 60%, 100%, and two extreme information spread speed (1 and infinite) to test the convergence of travelers' departure time choices and their performance in minimizing travel cost. It is found that neither providing no information nor proving full information to travelers is optimal for the total system travel time in the long run. For travelers with all others' information, they tend to follow the best departure time simultaneously and cause congestion around that time among themselves. This phenomenon is also found in our online experiment collecting participants' departure time choices in the presence of different levels of information provision based on the simulated social network configuration.

In summary, this work investigates travelers' departure time choices under the influence of social network information. We use a Bayesian belief updating approach to model travelers' day-to-day departure time choices with friends' information. Different social network structures, information coverage rate, and information spread speed are examined to study their effect on the transportation system performance. The results reveal that it is not optimal for travelers to know too much about the choices of others, or know too little under limited resources (like the road capacity). The results seem to imply that it is possible to optimize the transportation system performance by managing the type of information disseminating via different social network configurations and the information coverage rate in future studies.

References

Chen, R., Mahmassani, H.S., 2004. Travel time perception and learning mechanisms in traffic networks. *Transportation Research Record: Journal of the Transportation Research Board* 1894, 209-221.

Chorus, C.G., Arentze, T.A., Timmermans, H.J., 2009. Traveler compliance with advice: A Bayesian utilitarian perspective. *Transportation Research Part E: Logistics and Transportation Review* 45, 486-500.

Han, Q., Arentze, T., Timmermans, H., Janssens, D., Wets, G., 2011. The effects of social networks on choice set dynamics: Results of numerical simulations using an agent-based approach. *Transportation Research Part A: Policy and Practice* 45, 310-322.

Iryo, T., Yamabe, K., Asakura, Y., 2012. Dynamics of information generation and transmissions through a social network in non-recurrent transport behaviour. *Transportation Research Part C: Emerging Technologies* 20, 236-251.

Jou, R.-C., Kitamura, R., Weng, M.-C., Chen, C.-C., 2008. Dynamic commuter departure time choice under uncertainty. *Transportation Research Part A: Policy and Practice* 42, 774-783.

Kowald, M., Axhausen, K.W., 2012. Focusing on connected personal leisure networks: selected results from a snowball sample. *Environment and Planning-Part A* 44, 1085.

Parvaneh, Z., Arentze, T., Timmermans, H., 2012. Understanding Travelers' Behavior in Provision of Travel Information: A Bayesian Belief Approach. *Procedia-Social and Behavioral Sciences* 54, 251-260.

Ronald, N., Arentze, T., Timmermans, H., 2012. Modeling social interactions between individuals for

joint activity scheduling. *Transportation Research Part B: Methodological* 46, 276-290.
van den Berg, P., Arentze, T., Timmermans, H., 2013. A path analysis of social networks, telecommunication and social activity–travel patterns. *Transportation Research Part C: Emerging Technologies* 26, 256-268.