行政院國家科學委員會專題研究計畫　成果報告

結合高階動態車流模式與路網逐日調整模式構建平行動態路網模式

計畫類別：個別型計畫
計畫編號：NSC93-2211-E-009-032-
執行期間：93年08月01日至94年07月31日
執行單位：國立交通大學運輸科技與管理學系(所)

計畫主持人：卓訓榮

報告類型：精簡報告
報告附件：出席國際會議研究心得報告及發表論文
處理方式：本計畫可公開查詢

中　華　民　國 94年10月31日

Abstract

The traditional Dynamic Traffic Assignment (DTA) models could be classified into four groups: 1. Mathematical Programming, 2. Optimal Control, 3. Variational Inequality, and 4. Simulation-based Methodology. But the enroute path-switching behavior of a driver is rarely considered. Under the Intelligent Transportation System (ITS) environment, this study discuss the generalized decision making framework for the enroute path-switching behavior on within-day network dynamics, and presented an analytical model to describe the behavior by a macroscopic perspective.

Keywords — with-in day network dynamics, enroute path-switching behavior

Introduction

The static view of traffic flow prediction has been challenged recently by lots of scholars who have recognized the inherently dynamic nature of the route choice over a transportation network (Friesz et al., 1993). The Dynamic Traffic Assignment (DTA) has been developed for more than twenty years. Dynamic models differ from their static counterparts in view of the fact that they represent traffic variations over time (Chen and Hsueh, 1997). DTA considers the time-dependence decision variables and behaviors for transportation systems, as well as large-scale real-time and planning applications. From the past DTA literatures, the methodologies constructing DTA models could be classified into four broad groups: 1. Mathematical Programming, 2. Optimal Control, 3. Variational Inequality, and 4. Simulation-based Methodology (Peeta and Ziliaskopoulos, 2001). The first three groups are further labeled as analytical approaches. Most of the analytical approaches tend to focus on the user equilibrium and system optimal objectives, or some variants of them; the simulation-based DTA models use a traffic simulator to replicate the complex traffic flow dynamics, critical for developing meaningful operational strategies for real-time deployment. Mathematical programming DTA models formulate the problem in a discretized time-setting (Merchant and Nemhauser, 1978). The simulation-based DTA model uses of a simulator in a descriptive mode to determine the traffic flow propagation, most existing simulation-based models also use it as part of the search process to determine the optimal solution. Each methodology mentioned above involved different decision variables like behavior and system assumptions, and possesses different advantages and disadvantages with different solution and applications. The enroute path-switching behavior of a driver is rarely considered though.

The enroute path-switching behavior describes the behavior of a driver might switch his or her original path to an alternative one within the process of the travel based on the subjective estimation or external information. Adler and McNally (1994) investigated the pre-trip and enroute driver travel decisions in the presence of Advanced Traveler Information Systems (ATIS) with in-laboratory experiment. They discussed the enroute travel process with the node-based perspective, and set the choice situation as the current and alternate streets. The drivers will implement enroute path-switch assessment on each node (intersection) by perceived travel conditions and acquired network information (map). In Adler’s study, the authors implemented a microcomputer-based simulator to simulate the enroute travel decision making in a real-time environment; two diversion behavior models were obtained. The results revealed that drivers with higher levels of familiarity with travel conditions and network layout were less likely to divert and had a low reliance on information systems.

Mahmassani and Jayakrishnan (1991) presented another individual trip-making decision model for path selection decisions, both at the trip origin and enroute. The behavior rules reflected a boundedly-rational character, i.e. drivers looked for gains only outside a threshold. The driver only change from current path to the best path at current node if the trip time difference between the current path and the best path is larger then a threshold value. When it happens, the driver will change to the best path at the intersection. The threshold value may reflect perceptual factors, preferential indifference, or persistence and aversion to switching. These studies modeled the enroute diversion behavior with individual perspectives by the simulation-based approaches. Besides, they were lack of generalized and analytical models.

This study would discuss the generalized decision making framework for the enroute path-switching behavior on within-day network dynamics, and presented an analytical model to describe the behavior by a macroscopic perspective. This study is following by the notation that is adopted for constructing conceptual framework and model. Then the framework and dynamic model are presented sequentially. The final section is the perspectives for future studies.

Notation

$TT_{P,r,s}^{t,D}$: The travel time of path *P* connecting origin *r* and destination *s* at time interval t on day *D*.

$\mathbf{D}$: The set of days before day *D*.

$\|\mathbf{D}\|$: The amount of the set $\mathbf{D}$.

$ETT_{P,r,s}^{t,D}$: The expected value of the travel time of path *P* connecting origin *r* and destination *s* at time interval t on day *D*.

$\sigma_{P,r,s}^{t,D}$: The standard deviation of the travel time of path *P* connecting origin *r* and destination *s* at time interval *t* on day *D*.

α : A multiple parameter for setting the threshold value.

$\tilde{\mathbf{P}}_{r,s}^{t,D}$: The set of the all alternative paths for path *P* connecting origin *r* and destination *s* at time interval *t* on day *D*.

$TT_{P,r,s}^{t,D^*}$: The minimum travel time among all alternative paths for path P connecting origin r and destination s at time interval t on day D.

$H_{P,r,s}^{t,D}$: The number of vehicles of path P connecting origin r and destination s at time interval t on day D.

$I_{P,r,s}^{t,D}$: The inflow rate from origin r into path P connecting origin r and destination s at time interval t on day D.

$O_{P,r,s}^{t,D}$: The exit flow rate from path P connecting origin r and destination s into destination s during time interval t on day D.

$\beta_{P,r,s}^{t,D}$: The net flow rate switching into path P connecting origin r and destination s during time interval t on day D.

Δt : The length of a time interval by the unit time.

m_1 : A very small positive number relative to the term $\left| TT_{P,r,s}^{t,D} - ETT_{P,r,s}^{t,D} - \alpha \cdot \sigma_{P,r,s}^{t,D} \right|$.

m_2 : A very small positive number relative to the term $\left| TT_{P,r,s}^{t,D} - TT_{P,r,s}^{t,D^*} \right|$.

m_3 : A very small positive number relative to the term $\left| TT_{\tilde{P},r,s}^{t,D} - ETT_{\tilde{P},r,s}^{t,D} - \alpha \cdot \sigma_{\tilde{P},r,s}^{t,D} \right|$, $\tilde{P} \in \tilde{\mathbf{P}}_{r,s}^{t,D}$.

m_4 : A very small positive number relative to the term $\left| TT_{\tilde{P},r,s}^{t,D} - TT_{\tilde{P},r,s}^{t,D^*} \right|$, $\tilde{P} \in \tilde{\mathbf{P}}_{r,s}^{t,D}$.

m_5 : A very small positive number relative to the term $\left| TT_{P,r,s}^{t,D} - TT_{\tilde{P},r,s}^{t,D^*} \right|$, $\tilde{P} \in \tilde{\mathbf{P}}_{r,s}^{t,D}$.

α_P : The switching-out ratio of path P, $0 < \alpha_P \leq 1$.

Conceptual Framework

This study presents an enroute path-switching decision framework with a macroscopic and path-based competition perspective, which describes the interaction among the travel time information, enroute switch decision and flow adjustment. The framework is illustrated as Figure 1 within which the elements are discussed briefly as follows.

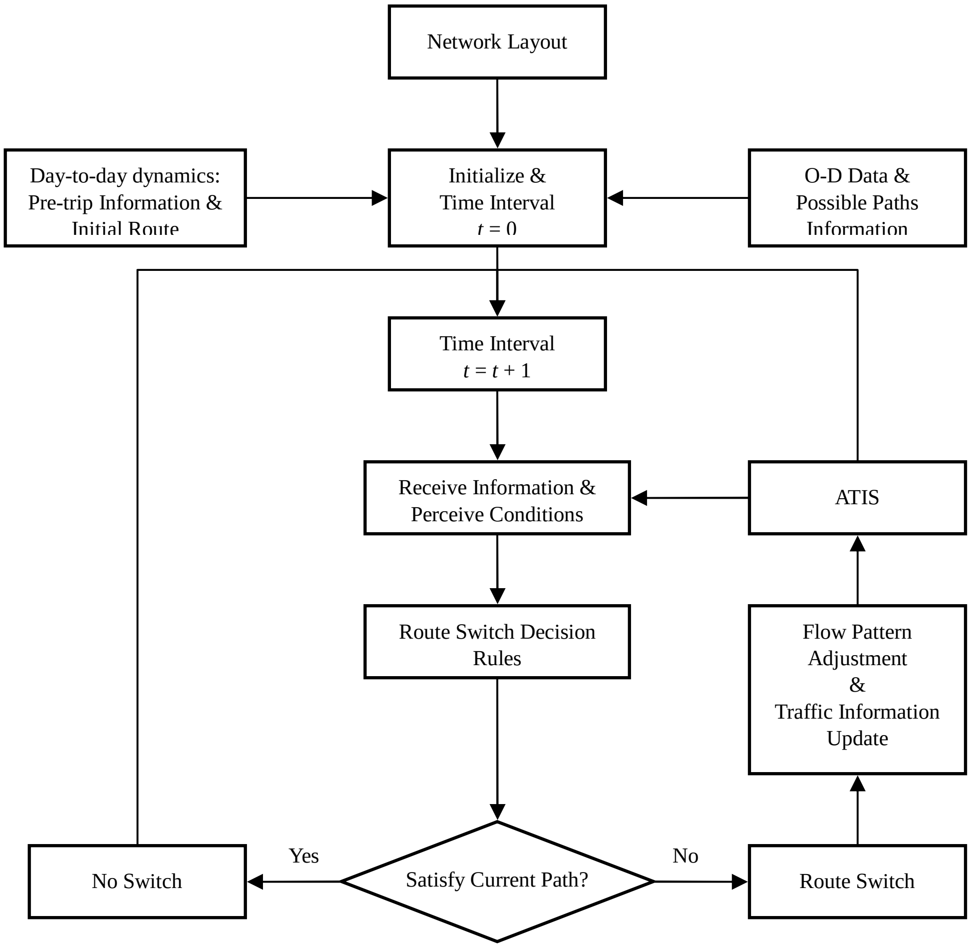

Figure 1. The conceptual framework of the enroute path-switching decision.

In the initiation of the network dynamics, the imposed information includes the subject network layout, Origin-Destination (O-D) demand, all possible paths, pre-trip assignment paths, flow pattern and so on. The drivers begin their trips and then the mechanism of the enroute path-switching decision takes place. During the process of decision making, the drivers with equipped vehicle would continuously updating information from Advanced Traveler Information System (ATIS) and perceive the current traffic conditions in the network along each path connecting an O-D pair. Based on the information and perception, drivers will evaluate the satisfaction level of the current path. With a satisfying current path, drivers do not switch route to another;

otherwise, the driver will switch to a better route. After the enroute path-switching behavior each time interval, the network flow pattern and travel information are updated and imposed into database of ATIS, which also provide the net network information for drivers within the network. After the updating process, the time interval goes to the next one, and the interactive mechanism keeps working during each time interval.

Modeling the Enroute Switch Behavior

In the section, the model for describing the enroute path-switching decision behavior that would influence the flow pattern at each time interval is presented. This section includes two subsections; the first is one describing the switch behavior rules and the other presents the enroute switching dynamic model.

Switch Behavior Rules

In this study, macroscopic approach is implemented to discuss drivers' behavior of enroute path switching at each time interval on some day, which refers to the with-in day network dynamics. For a path-based perspective, drivers along a specific path connecting an O-D pair would switch into another path and drivers along alternative paths would also switch into the path, the mechanism depends on the variation of traffic conditions. The former switching behavior is described with the switching-out behavior rule and the later is the switching-in behavior rule, which will be discussed more detail in the next paragraphs of this section.

This investigation assumes that the satisfaction level for a specific path is evaluated by whether the travel time of the path is more than particular thresholds of the switching-out behavior rule or not. When the satisfaction level of a path is more than its thresholds, drivers would switch to the best alternative path. The thresholds are assumed as two parts of which one is the expected value of the travel time of the path plus α times the standard deviation of the travel time of the path, and the other is the value of the minimum travel time among all alternative paths for the path. The expected value and standard deviation of the travel time of a specific path *P* at time interval *t* on day *D* can be calculated by the historical travel times provided by ATIS at the same time interval on the days before day *D*, and their mathematical equations are expressed as $ETT_{P,r,s}^{t,D} = \frac{\sum_{d=1}^{d=D-1} TT_{P,r,s}^{t,D}}{\|\mathbf{D}\|}$ and $\sigma_{P,r,s}^{t,D} = \sqrt{\frac{\sum_{d=1}^{d=D-1}\left(TT_{P,r,s}^{t,D} - ETT_{P,r,s}^{t,D}\right)^2}{\|\mathbf{D}\|-1}}$ respectively. The minimum travel time among all alternative paths at the time interval *t* on day *D* is provided by ATIS, and is expressed as $TT_{P,r,s}^{t,D}$. Then the complete thresholds for the switching-out behavior rule are $TT_{P,r,s}^{t,D} - ETT_{P,r,s}^{t,D} - \alpha \cdot \sigma_{P,r,s}^{t,D} \leq 0$ and $TT_{P,r,s}^{t,D} - TT_{P,r,s}^{t,D^*} \leq 0$. If these two thresholds were not satisfied, drivers along the path would switch to the best alternative path. The volume of the switching-out drivers may be all or part of the volume of the drivers driving along the path at the last time interval, which is governed by the drivers' characteristics such as the radical degree, the persistence level and son one, and is expressed as α_P.

It is similar to the switching-out behavior rule that the switching-in behavior rule is described as two thresholds and a particular condition for drivers along alternative paths switching into path *P*. Let all alternative path of the path *P* be expressed as $\tilde{P}$, $\tilde{P} \in \tilde{\mathbf{P}}_{r,s}^{t,D}$. When the travel time of path $\tilde{P}$ at time interval *t* on day *D* is more than the expected value of the travel time of it plus α times the standard deviation of the travel time as well as the minimum travel time among all alternative paths (including path *P*) of it, i.e. $TT_{\tilde{P},r,s}^{t,D} - ETT_{\tilde{P},r,s}^{t,D} - \alpha \cdot \sigma_{\tilde{P},r,s}^{t,D} > 0$ and $TT_{\tilde{P},r,s}^{t,D} - TT_{\tilde{P},r,s}^{t,D^*} > 0$, drivers would switch from the alternative path $\tilde{P}$. Furthermore, a particular condition, when the travel time of path *P* is equal to the minimum travel time among all alternative paths of the path $\tilde{P}$, $TT_{P,r,s}^{t,D} = TT_{P,r,s}^{t,D^*}$, it represents that path *P* is the best alternative path for path $\tilde{P}$. All or part of drivers along path $\tilde{P}$ at the last time interval would switch into path *P* from path $\tilde{P}$ at the current time interval, and the switching-out ratio for path $\tilde{P}$ is expressed as $\alpha_{\tilde{P}}$.

Enroute Switching Dynamic Model

After introducing the switching-out and switching-in behavior rules, a switching dynamic model can be presented, which describes macroscopically the adjustment of the flow pattern resulted from the effects of the enroute switching behaviors. At the beginning of the modeling, the flow conservation law is introduced by the assumption that no enroute switching behavior arises, and the standard form by discrete perspective is as eq.(1):

$$H_{P,r,s}^{t,D} = H_{P,r,s}^{t-1,D} + \left(I_{P,r,s}^{t,D} - O_{P,r,s}^{t,D}\right) \cdot \Delta t, \tag{1}$$

where $H_{P,r,s}^{t,D}$ is the number of vehicles of path *P* connecting origin *r* and destination *s* at time interval *t* on day *D*, $I_{P,r,s}^{t,D}$ is the inflow rate from origin *r* into path *P* during time interval *t* on day D, $O_{P,r,s}^{t,D}$ is the exit flow rate from path *P* into destination *s* during time interval *t* on day *D*, and Δt is the length of a time interval by the unit time. After relaxing eq.(1) by adding a net flow rate $\beta_{P,r,s}^{t,D}$ which represents drivers decision of enroute switch into path *P* during time interval *t* on day *D*, eq.(1) can be modified as eq.(2).

$$H_{P,r,s}^{t,D} = H_{P,r,s}^{t-1,D} + \left(I_{P,r,s}^{t,D} - O_{P,r,s}^{t,D} + \beta_{P,r,s}^{t,D}\right) \cdot \Delta t \tag{2}$$

By rewriting eq.(2) as eq.(3) and limiting Δt toward zero, a continuous and dynamic model is presented as eq.(4) by the basic principle of the integration. Which describes that the flow pattern would change and adjust with time because of the effects of the enroute path-switching behaviors as well as the variability of the inflow rate and exit flow rate.

$$\frac{H_{P,r,s}^{t,D} - H_{P,r,s}^{t-1,D}}{\Delta t} = I_{P,r,s}^{t,D} - O_{P,r,s}^{t,D} + \beta_{P,r,s}^{t,D} \tag{3}$$

$$\frac{dH_{P,r,s}^{t,D}}{dt} = I_{P,r,s}^{t,D} - O_{P,r,s}^{t,D} + \beta_{P,r,s}^{t,D} \tag{4}$$

In the eq.(4), the term of the net flow rate, $\beta_{P,r,s}^{t,D}$, can be determined by the above switching-out and switching-in behavior rules, and be represented mathematically as eq.(5).

$$\beta_{P,r,s}^{t,D} = \left\{ -\alpha_P \cdot H_{P,r,s}^{t-1,D} \cdot MAX \left(\frac{TT_{P,r,s}^{t,D} - ETT_{P,r,s}^{t,D} - \alpha \cdot \sigma_{P,r,s}^{t,D}}{\left| TT_{P,r,s}^{t,D} - ETT_{P,r,s}^{t,D} - \alpha \cdot \sigma_{P,r,s}^{t,D} \right| + m_1} + \frac{TT_{P,r,s}^{t,D} - TT_{P,r,s}^{t,D^*}}{\left| TT_{P,r,s}^{t,D} - TT_{P,r,s}^{t,D^*} \right| + m_2} - 1, 0 \right) \right.$$

$$+ \sum_{\tilde{\mathbf{P}}_{\mathbf{r,s}}^{\mathbf{t,D}}} \alpha_{\tilde{P}} \cdot H_{\tilde{P},r,s}^{t-1,D} \cdot MAX \left(\frac{TT_{\tilde{P},r,s}^{t,D} - ETT_{\tilde{P},r,s}^{t,D} - \alpha \cdot \sigma_{\tilde{P},r,s}^{t,D}}{\left| TT_{\tilde{P},r,s}^{t,D} - ETT_{\tilde{P},r,s}^{t,D} - \alpha \cdot \sigma_{\tilde{P},r,s}^{t,D} \right| + m_3} + \frac{TT_{\tilde{P},r,s}^{t,D} - TT_{\tilde{P},r,s}^{t,D^*}}{\left| TT_{\tilde{P},r,s}^{t,D} - TT_{\tilde{P},r,s}^{t,D^*} \right| + m_4} \right. \tag{5}$$

$$\left. \left. - \frac{TT_{P,r,s}^{t,D} - TT_{\tilde{P},r,s}^{t,D^*}}{\left| TT_{P,r,s}^{t,D} - TT_{\tilde{P},r,s}^{t,D^*} \right| + m_5} - 1, 0 \right) \right\} \Big/ \Delta t$$

The first maximum term of the eq.(5) describes that when the travel time of path *P* at time interval *t* on day *D* is more than the expected value of the travel time of it plus α times the standard deviation of the travel time and the minimum travel time among all alternative paths of it, drivers along path *P* would decided to enroute switch from it. The switching-out ratio is determined by the number of vehicles of the path at the last time interval $H_{P,r,s}^{t-1,D}$ and α_P which represents the drivers' characteristics and attitudes. The secondary maximum term of the eq.(5) describes that when the travel time of the alternative path $\tilde{P}$ at time interval *t* on day *D* is more than the expected value of the travel time of it plus α times the standard deviation of the travel time as well as the minimum travel time among all alternative paths (including path *P*) of it in addition to the travel time of path *P* equal to the minimum travel time among all alternative paths of path $\tilde{P}$, the drivers along the alternative path $\tilde{P}$ would decided to enroute switch into path *P*. And the switching-out ratio is determined by $H_{P,r,s}^{t-1,D}$ and $\alpha_{\tilde{P}}$. The terms of m_1, m_2, m_3, m_4 and m_5 are used to avoid the denominator of each fraction being zero.

Therefore, the system equation of eq.(4) and eq.(5) are the presented dynamic model for describing the enroute path-switching behaviors and the effects of them on the adjustment of the flow pattern in a transportation network encompassing the technology of ATIS.

Reference

1. Adler, Jeffrey L. and McNally, Michael G., "In-laboratory Experiments to Investigate Driver Behavior under Advanced Traveler Information System", Transportation Research 2C, pp.149-164, 1994.
2. Chen, Huey-Kuo and Hsueh, Che-Fu, "A model and an Algorithm for the Dynamic User-Optimal Route Choice Problem", Transportation Research 32B, pp.219-234, 1998.
3. Friesz, T.L., Bernstein, D., Smith, T.E., Tobin, R.L., Wie, B.W., "A Variational Inequality Formulation of the Dynamic Network User Equilibrium Problem", Operations Research 41, pp.179-191, 1993.
4. Mahmassani, H.S. and Jayakrishnan, R., "System Performance and User Response under Real-time Information in a Congested Traffic Corridor", Transportation Research 25A, pp.293-307, 1991.
5. Merchant, D.K. and Nemhauser, G.L., "A Model and an Algorithm for the Dynamic Traffic Assignment Problems", Transportation Science 12, pp.200-207, 1978.
6. Peeta, Srinivas and Zhou, Chao, "Robustness of the off-line a priori stochastic dynamic traffic assignment solution for on-line operations", Transportation Research Part 7C, pp.281-303, 1999
7. Peeta, Srinivas and Ziliaskopoulos, A.K., "Foundations of Dynamic Traffic Assignment: the Past, the Present and the Future", Networks and Spatial Economics 1, pp.233-265, 2001.