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Route-Choice Models Reflecting the Use of Travel Navigation Information in a Vehicle-Based Microscopic Simulation System

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Advance Traveler Information Systems are anticipated to have significant impacts on individual driver behaviors through disseminating routing information to drivers. Consequently, diversions of traffic between different routes might result from drivers having more information available to them. To evaluate the impacts of traveler information through microscopic simulation, it is essential and critical to build route choice models that are expected to correctly represent the use of traveler information by various categories of drivers. Some related studies indicated that using shortest path guidance alone is unlikely to allow simulation algorithms to take into account the impact of real-time information on drivers' route choices. Urban commuters’ route choices are usually based on the perceived delay between actual arrival time and preferred arrival time (indifference band of route delay). In this paper, the authors attempt to build the structure of models for pre-trip and en route choices reflecting the effects of traveler information in a lane-vehicle-based microscopic simulation system. In the proposed models, a fuzzy set is used to represent the effect of an indifference band of route delay on the tendency for a specific category of drivers to change routes. Fuzzy sets are used to describe the reactions of drivers to traveler information with respect to their tendency to change routes. This methodology shows potential to more realistically represent the effects of real-time information on route choice than can be accomplished using binary choice models.
INTRODUCTION

Advanced Traveler Information Systems (ATIS) are expected to have significant impacts on individual driver behaviors through disseminating routing information to drivers. Using ATIS, accurate, real-time information about the characteristics of the travel environment can be provided to travelers before their departure and while they are en route. The goal is to alter travel behavior in such a way as to improve the individual driver’s efficiency and the overall characteristics of the travel environment, resulting in accessibility gains for all drivers [Vaughn, et al 1995]. For example, the benefits of ATIS in reducing congestion and the potential of large savings in travel time and fuel consumption are based on real-time diversions of traffic from main facilities (e.g., the Interstate system) to lower-class roads (e.g., arterials and the local street system). The effectiveness of ATIS depends on drivers’ reactions to information provided, which is affected greatly by the degree to which the information is accurate. Consequently, the assumptions about real-life route choice behavior in dynamic traffic assignment have received increasing attention recently. One study indicates that using shortest path guidance is likely to fail if the guidance strategy ignores the impact of drivers’ reactions to information [Kaysi, et al 1995].

Mahmassani and Tong’s investigation [Mahmassani and Tong 1986] indicates that commuters’ route choices are usually based on perceived delay, the difference between actual arrival time and preferred arrival time, called tolerable schedule delay. This implies that drivers do not switch to another route that is predicted to have minimum
travel cost if the estimated delay falls into the range they can tolerate, called *indifference band of route delay*. This is especially true for urban commuters.

Iida, Akiyama and Uchida’s (Iida et al., 1992) experiment disclosed an interesting attribute of route choice behavior: drivers may consider other drivers’ behaviors when choosing routes. They believe that when all travelers are given access to the same network information and if some of them react to it, those staying on the current route may benefit from other drivers’ leaving. These drivers are usually those who are very familiar with the routes based on their driving history. Polydoroulou, Ben-Akiva and Kaysi’s survey [Polydoroulou, et al 1994] shows that about 75% of the sample drivers are very familiar with at least two different routes to work and around 50% are strongly willing to try new routes to avoid traffic delays. From another survey sample of drivers, they also found that 63% of them rarely or never change their planned route, while 16% often make such a change. 37% of drivers indicated that they often listen to radio traffic reports, and 27% usually follow the recommendations. Only 25% think that radio traffic reports are reliable, whereas 22% consider them irrelevant. Among drivers who listen to radio traffic reports, 20% often change their routes after listening, whereas 50% completely ignore traffic reports when they are different from their own observations.

Based on these studies, the assumption used in most route choice models—that travelers always choose the route with the minimum travel time when route information is available—is not consistent with observed behavior. In a vehicle-based microscopic simulation system that considers the impact of traveler information on traffic assignment, it is necessary to build a routing choice model that predicts route-change behavior as a function of available information. The criterion of an indifference band of trip delay may
be used to both objectively evaluate the potential impact of ATIS on route choice, so that vehicle-based microscopic simulation systems may provide higher accuracy of traffic information by better simulating route choice behavior. This paper presents a structure of a route choice model based on insight from the authors’ study of observed travel behaviors (e.g., lane-choice and lane changing behaviors) [Wei, 1999]. A fuzzy set is used to reflect different effects of an indifference band of route delay on driver tendency to change routes. Fuzzy sets are also used to model driver response to traveler information with respect to the tendency to change routes. This methodology seems to better represent observed driver behavior than binary choice models.

ROUTE CHOICE IN A LANE-VEHICLE-BASED SIMULATION PROCESS

A lane-vehicle-based simulation process describes a vehicle’s position during its journey in an urban street network. Based on observations and study of lane-choice and lane-changing models [Wei, Meyer, Lee and Feng 1999, and Wei, Lee, and Li 1999], route choice behavior plays a critical role in assignment of a vehicle to a specific lane during each simulation time interval (termed as simulation time step in the paper). To clarify the relationship between route choice and other travel behaviors in a lane-vehicle-based simulation process, primary simulated states are defined as follows and illustrated in Figure 1.
**Origin State**: Defines the original location of a simulated vehicle (where it enters the simulated network), the departure time, and the destination. The vehicle enters the street network at the nearest intersection to the original location.

**Entering State**: Defines the intended route from the origin to the destination at the time of departure. In reality, a driver usually chooses his/her route before starting the trip. The driver makes the decision based on updated route information from media such as the

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**Figure 1. Illustration of Primary Simulation States**

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**Legend**: One Way Street
Internet or previous experience. In the simulation, the pre-trip route is assumed to be the shortest path (by travel time) resulting from the latest available roadway traffic conditions, termed as *current network condition*. This state is simulated only when a vehicle is generated.

**Lane-Choice State**: Defines a specific lane whenever the vehicle enters a street segment from a turning entry at an intersection. Lane-choice decision is simulated depending on the driver's pre-trip route or en-route plan [Wei, Lee, and Li, 1999]. This state is simulated whenever a vehicle is going to turn in a street segment from an intersection.

**Car-Following State**: Defines vehicle location, speed, spatial and temporal relation with the preceding vehicle (if it exists), as well as its reaction to any changes in the preceding vehicle's speed during each simulation time step. Since car-following models have been extensively considered in the literature, no new attempts in this area were pursued in the study. This state is simulated during any simulation time step.

**Lane-Changing State**: Recognizes the vehicle's request and decision for changing lanes, lane-changing type (mandatory, preemptive, or discretionary), lane-changing conditions to determine whether acceptable gaps are available for changing lanes, and lane-changing maneuvers. Location, acceleration, speed, and duration are estimated at each simulated time step during a lane change. This state is simulated as long as the vehicle is moving within a street segment and not within an intersection.

**New-Entering State**: Determines the vehicle's lane choice if the travel goes through the current intersection and continues to the downstream street segment. Then, it proceeds to a lane-choice state as above described if necessary.
En route Route Choice State: Updates the vehicle’s remaining route if and only if the current network condition is changed, updated traveler information is available, and the destination has not been reached. This state is simulated when the vehicle is entering a downstream street segment.

Exiting State: Checks the vehicle's current lane and its intention as it approaches the end of the current street segment (next intersection) to go straight, turn, or reach its destination. If the approaching intersection is the destination, the vehicle's trip is ended and is no longer traced. Its recorded locations, clock time, speeds, accelerations, and maneuvers are stored in the database when any action occurs that leads to the change of the vehicle's state. This state is simulated when the vehicle is approaching the downstream intersection.

Figure 2 shows the flowchart of the simulation process of an individual vehicle’s trip. It also shows the relationship between pre-trip and en route route-choice models and other travel behavior models in the simulation process. The simulation process iterates until the vehicle reaches its destination. A driver’s reaction to traveler information (or updated route information) would cause a change of route plan. All trips, collectively, form macroscopically traffic flows on each link in a network. Thus, changes of pre-trip and en route route contribute to diversions of traffic between different streets. As a result of changes in the current network condition, a driver might adjust lane-choice, lane-changing, and even car-following behaviors during the remainder of the trip. In turn, diversions of traffic provide the basis for updating the current network conditions and route choice information.
Each state can also be understood as a major travel behavior that can be described by a corresponding sub-model, as shown in Figure 2. Sub-models for pre-trip and en route route choice behaviors are discussed in the following sections. Other behaviors mentioned above such as lane-choice, lane-changing and car following behaviors are beyond of the scope of this paper. More information is available elsewhere. [Wei Meyer, Lee and Feng 1999, and Wei, Lee, and Li 1999].

SPECIFIC CONCEPTS USED IN ROUTE CHOICE PROBLEM DISCUSSION

Some specific terms and mathematical functions used in the discussion of the route choice problem and the development of the simulation algorithm are described as follows:

Classifications of Drivers

All drivers are generally classified into two categories—aggressive drivers and conservative drivers, denoted by \( Y_1=1 \) and \( Y_1=0 \), respectively. Meanwhile, all drivers are also either information receivers or information neglecters (i.e., drivers who do not receive information), denoted by \( Y_2 =1 \) and \( Y_2=0 \), respectively. To clearly describe a driver’s classification as a combination of these two parameters, a driver can be denoted by the following symbols.

- \( S_1: Y_1 = 1, \ Y_2 = 1 \) (an aggressive driver who receives information)
- \( S_2: Y_1 = 1, \ Y_2 = 0 \) (an aggressive driver who doesn’t receive information)
- \( S_3: Y_1 = 0, \ Y_2 = 1 \) (a conservative driver who receives information)
- \( S_4: Y_1 = 0, \ Y_2 = 0 \) (conservative driver who does not receive information)
Figure 2. Flowchart of the Simulation Process of a Vehicle’s Trip
Suppose $\varphi_1$ percent of the O-D trips $T_{ij}$ between zones $I$ and $J$ are assumed to be aggressive drivers, while $(1-\varphi_1)$ percent are conservative drivers. A driver generated during the simulation process can be randomly determined as an aggressive or conservative driver. Assume that a random number $\omega_1$ between $[-\infty, +\infty]$ is assigned to the driver to represent the driver’s aggressiveness. The $\omega_1$ can be converted to a value between 0-100 using the $\text{logsig}$ neural function:

$$DA_{1_{nt_{-}il}} = \frac{100}{1 + e^{-\omega_1}}$$  \hspace{1cm} (1)$$

Then, classification of the driver is described by $Y_1$ as:

$$Y_{1(nt_{-}il)} = \begin{cases} 
1 & \text{if} \quad 0 \leq DA_{1_{nt_{-}il}} \leq \varphi_1 \\
0 & \text{if} \quad \varphi_1 < DA_{1_{nt_{-}il}} \leq 1 
\end{cases}$$  \hspace{1cm} (2)$$

Similarly, suppose $\varphi_2$ percent of the O-D trips $T_{ij}$ between zone $I$ and $J$ are assumed to be information receivers, while $(1-\varphi_2)$ percent are information neglecters. A driver generated during the simulation process can be randomly determined as an information receiver or neglecter. Assume that a random number $\omega_2$ between $[-\infty, +\infty]$ is assigned to the driver to represent the driver’s attitude toward information (active or not). The $\omega_2$ can be converted to a value between 0-100 using the $\text{logsig}$ neural function:

$$DA_{2_{nt_{-}il}} = \frac{100}{1 + e^{-\omega_2}}$$  \hspace{1cm} (3)$$

Then, the classification of the driver is described by $Y_2$ as:

$$Y_{2(nt_{-}il)} = \begin{cases} 
1 & \text{if} \quad 0 \leq DA_{2_{nt_{-}il}} \leq \varphi_1 \\
0 & \text{if} \quad \varphi_1 < DA_{2_{nt_{-}il}} \leq 1 
\end{cases}$$  \hspace{1cm} (4)$$
**Driver’s Primary Route**

A primary route simulates a driver’s familiar route or route suggested based on average traffic conditions (such as a route provided by the MapQuest website). It is defined as the minimum travel cost route estimated under uncongested conditions, i.e., each link in the network operates at level of service C or better. In this case, the volume to capacity ratio, $v/c$, is assumed to be 0.5 or less, and the average speed is assumed to be the posted speed.

**Dynamic/Predicted Best Route**

A dynamic best route simulates the dynamically updated route for a specific vehicle during a given simulation step. In other words, it is the minimum travel cost route from the current vehicle location to the destination, based on the simulated traffic condition at time $t$. If the vehicle is en route at simulation time step $t$, the cost of the predicted best route includes two parts: experienced route—travel cost of the driver experienced from origin to the current position and dynamic best route—estimated travel cost of rest of route from the current position to the destination based network condition at $t$. In reality, the nearest place where the driver is able to change the current route is the immediate downstream intersection.

**Driver’s Current Route**

A driver’s current route is the route determined by the last updated route. A driver starts each trip with a primary route that is determined before departure. The primary route is also the driver’s current route when the vehicle is entering the street.
network. When the vehicle reaches the immediate downstream intersection, its dynamic best route is determined and provided to the driver. If the predicted best route is different from the primary route, and the driver is disposed to change routes based on the driver's behavioral characteristics, then the driver’s current route will be replaced with the predicted best route. Similarly, the driver’s new route may be replaced by a newer predicted best route at any subsequent intersection, provided the newest predicted best route is preferable to the current route at the time.

**Indifference Band of Route Delay (IBRD):**

As described earlier in the paper, indifference band of route delay (IBRD) simulates a driver's tolerable difference in time between the current route and the dynamic best route resulting from the instant network traffic conditions given by the traveler information system (when the former is greater than the latter). According to Mahmassani and Chang’s study [Mahmassani, et al 1985], the width of the indifference band of route delay is suggested to be 10 minutes; Knippenberg’s study indicates the suggested value of 18 minutes [Knippenberg 1986]. However, the trip length should be associated with the values of IBRD. On a 60-minute trip, for example, 10 minutes is not a big difference. For a 20-minute trip, on the other hand, a 10-minute improvement is meaningful to the driver. Fuzzy sets are used in dealing with application of this concept in the simulation algorithm as described in the following sections.
STRUCTURE OF ROUTE CHOICE MODELS

According to Mahmassani and Tong’s investigation [Mahmassani and Tong 1986], commuters’ route choices are usually based on the perceived delay between actual arrival time and preferred arrival time, called schedule delay. This implies that a driver’s route choice can be assumed to be dependent on an indifference band of route delay, i.e., the delay between driver’s current route and predicted best route. Since the threshold value of indifference band of route delay varies with areas and different categories of drivers, it is hard to determine a specific threshold for use. For instance, Mahmassani and Chang’s study [Mahmassani, et al 1985] shows that the width of indifference band of route delay is suggested to be 10 minutes; Knippenberg’s study indicates the suggested value of 18 minutes [Knippenberg 1986]. The authors recommend a method using fuzzy sets to determine the likelihood of a route change if the estimated delay falls into the width of indifference band of route delay.

Figure 3 illustrates the structure of route choice model with two categories of drivers. In the pre-trip route choice model, the indifference band of route delay is the difference in travel time between the driver’s primary route $\gamma_p$ and the dynamic best route $\gamma_b$. In en route route-choice mode, it is the difference in travel time between the driver’s current route $\gamma_c$ and the dynamic best route.

The likelihood of changing routes is defined to reflect the driver’s willingness to alter their route (i.e., to the predicted best route). Assume that the value ranges from 0 to 10, representing the strength of the driver’s willingness to change routes, 10 representing the most willing and 0 representing the least willing. The control variable is defined as $\Delta C = (Cost\ of\ Current\ Route \ – \ Cost\ of\ the\ Predicted\ Best\ Route)*(30/Primary\ Route$.
Figure 4(a) displays a diagram of membership functions (fuzzy sets) of the control variable for the width of IBRD at 0 min, 5 min, and 10 min per 30-minute primary trip, respectively, and the corresponding output curves (probability versus tendency). When a specific $\Delta C$ is obtained (e.g., 7 minutes) and input into the fuzzy system, the output indicates that the driver’s tendency of route switch is valued as 6.1, as shown in Figure 4(b). In other words, the driver’s degree of willingness to switch to the instant best route is measured as 6.1 out of 10. If the criterion for deciding to change routes is 6.5, then the driver decides to change routes.
a. Design of Fuzzy Set and Output Plots

Figure 4. Demonstration of the Route Choice Model Using the Fuzzy Sets

b. Estimate of the Tendency of Route Switch

Value of Tendency = 6.1
The driver’s degree of tendency to switch route is 6.1 out of 10

Figure 4. Demonstration of the Route Choice Model Using the Fuzzy Sets
The heuristic rules of the pre-trip and en route route-choice models are described as follows.

**Pre-trip Route-Choice Model**

Before a vehicle begins a trip, the following rules are applied:

- If \((Y_1 = 1, Y_2 = 1)\), then the driver chooses the dynamic best route;
- If \((Y_1 = 1, Y_2 = 0)\), then the driver chooses the primary route.
- If \((Y_1 = 0, Y_2 = 1)\), then the driver’s choice of the dynamic best route is dependent on the tendency of the driver to change routes, as illustrated in Figure 4. It is assumed that an aggressive driver is very familiar with the network and can judge the best route instantly by experience.
- If \((Y_1 = 0, Y_2 = 0)\), then the driver chooses the primary route. The conservative drivers without notification of updated route information are assumed to be following their habitual routes all the time and are not willing to try other routes.

**En-Route-Choice Model Using Fuzzy Sets**

Whenever a simulated vehicle passes through an intersection and is entering a downstream segment, the following rules are applied:

- If \((Y_1 = 1, Y_2 = 1)\), then the driver switches to the dynamic best route;
- If \((Y_1 = 1, Y_2 = 0)\) or \((Y_1 = 0, Y_2 = 1)\), then the driver’s choice of the dynamic best route is dependent on the tendency of the driver to change routes, as illustrated in Figure 4. It is assumed that an aggressive driver is very familiar with the network
and can judge the best route instantly by experience. If this is the case, the condition \((Y_1 = 0, Y_2 = 1)\) applies to the rule.

- If \((Y_1 = 0, Y_2 = 0)\), then the driver is in the primary route all the time. The conservative drivers without notification of updated route information are assumed to be following their habitual routes all the time and are not willing to try other routes.

**SUMMARY**

In this paper, the route choice problem is explored for a lane-vehicle-based microscopic simulation system. Since different categories of drivers have different reactions to the traveler routing information, traditional models that assume every driver is very familiar with the network and always chooses the shortest path are not applicable to the study of the impact of traveler information on drivers’ route choice behaviors. The methodology proposed in this paper attempts to more realistically simulate route choice behavior. For instance, it is assumed that all drivers must have their primary routes before the trips, based on route information (e.g., from the Internet) or from experience. When they receive updated routing information while en route, aggressive drivers are more likely than conservative drivers to follow the advice. Aggressive drivers who are not exposed to the updated information may still adjust their primary route based on differences between expected and experienced traffic characteristics. But route changes also depend on familiarity with the road network. In general, if a driver on the route decides to change routes, the change cannot occur until the next downstream intersection is reached.
More importantly, drivers do not switch to another route that is predicted to have minimum travel cost if the estimated delay falls into the indifference band of route delay. Different categories of drivers have varied criteria of the width of indifference band of route delay. Thus, fuzzy sets may be an appropriate theoretical method to be used for estimation of a specific driver’s tendency to change routes. Further investigation and study of threshold values of the width of the indifference band of route delay may be needed for the areas of interest.

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