Graded-information feedback strategy in two-route systems under ATIS

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Abstract: In consideration of the constraint of the advanced traveler information systems (ATIS) detecting accuracy and the time delay of information feedback systems, a novel approach named graded-information feedback strategy is proposed and applied into a two-route scenario. The approach adopts the fuzzy C-means clustering algorithm to classify road traffic conditions based on flux, mean velocity, and density. Then, each cluster center is fixed on. Furthermore, real-time traffic conditions on each route could be judged by the preceding cluster centers. Results of judgment would be displayed on variable message signs to guide the successors at the entrance to make reasonable route-choices. Meanwhile, a cellular automaton model is adopted to investigate the correlation between efficiency of two-route systems, number of clustering, and travelers' route choice behavior. Compared with the conventional strategies, the simulation shows that the innovative information feedback strategy can evidently improve utilization efficiency of road networks.

Key words: traffic flow; graded-information feedback; two-route; fuzzy cluster; cellular automaton model

1 Introduction

In recent years, there has been a growing interest in design and deployment of advanced traveler information systems (ATIS). As key part of ATIS, information feedback strategies have attracted great interest of transportation scholars (Eran et al. 2013a; Cristea et al. 2014; Eran et al. 2013b). The road service efficiency can be greatly improved by means of an applicable information feedback strategy. Although people are full of expectation of ATIS, traffic condition would become more serious if an inappropriate information feedback strategy is adopted. It is an essential task in the field of road traffic to find an optimal and efficient information feedback strategy (Wahle et al. 2002; Zhao et al. 2013).

Thus, several conventional information feedback strategies have been proposed. These strategies mainly consist of three types; travel time feedback strategy (TTFS) (Wahle et al. 2000), mean velocity feed-
back strategy (MVFS) (Lee et al. 2001) and congestion coefficient feedback strategy (CCFS) (Wang et al. 2005). It has been proven that MVFS is more effective than TTFS, which is a lag effect approach and is impossible to provide travelers with the current situation of each route. Meanwhile, CCFS is more effective than MVFS, the core of which is to define the congestion coefficient creatively. Regardless of the fact that CCFS promotes the efficiency of the road networks, it needs higher detection precision and more computing resources of ATIS to compute the congestion coefficient. Based on three strategies above, Dong et al. (2010a; 2010b; 2010c) put forward to a corresponding angle feedback strategy (CAFS), a vehicle number feedback strategy (VNFS) and a prediction feedback strategy (PFS). Chen et al. (2012a; 2012b; 2012c) put forward to a vehicle’s length feedback strategy (VLFS), time flux feedback strategy (TFFS), and an exponential function feedback strategy (EFFS). Tobita and Nagatani (Tobita et al. 2012) put forward to a tour-time feedback strategy.

These information feedback strategies adopted various traffic flow feedback factors to improve the capacity and performance of road networks to some extent. In order to make research work more conveniently, it is commonly assumed that ATIS can acquire real-time and precise traffic information. In practice, traffic information is gathered from each vehicle, and is transmitted to traffic center to be processed, and then is distributed to each road user. As a result of the above whole process, the delay of feedback information will be inevitable. In addition, traffic information is restricted to the level of ATIS detecting accuracy, and impracticable to provide completely precise information.

Furthermore, Meneguzzer and Olivieri (2013) studied the day-to-day route choice dynamics in a simple three-route network with limited feedback information. Hino and Nagatani (2014) studied the traffic behavior in the case which has a bottleneck on a route in the two-route traffic system with real-time information. Shiftan et al. (2011) evaluated the potential benefits from pre-trip travel time information provision by gaining insights into and better understanding of the factors affecting the route-choice behavior of travelers. Elia and Shiftan (2010) pointed out that travelers made route-choice relying on both real-time information and their historical experience. Bekhor and Albert (2014) demonstrated that certain sensation seeking domains alongside traditional variables played an important role in route choice behavior with pre-trip travel time information.

The above researches reveal the complex relationship between route-choice behavior and real-time feedback information. But, it is a conventional presumption which is commonly called the maximum utility theory in the former information feedback strategies that travelers would always choose the shortest-time cost one of the routes according to feedback information. As a matter of fact, detailed and precise feedback information is not required because travelers usually take feedback information only as reference. Consequently, it is a reasonable and practical approach to provide road users with graded-information to minimize their personal travel time, which is qualitative based on numerical information about the traffic conditions. Both delay of information processing and detection error of ATIS are ignored in the graded-information. The discrete choice model is adopted to imitate traveler’s route-choice behavior instead of the maximum utility theory. Of course, the emphasis of this study is on the graded method of traffic information and performance analysis of the graded-information feedback strategy (GIFS) in two-route scenario.

The remainder of this paper is arranged as follows. In section 2, the VDR model and a two-route scenario are briefly introduced, and then graded-information rules on the basis of fuzzy C-means clustering algorithm are depicted in detail. In section 3, factual simulation results are presented and results are discussed on the comparison of TTFS. In the last section, we make conclusions and suggestions.

2 Graded-information feedback strategies

2.1 VDR mechanism

Compared with the NS mechanism, which is the most popular and simplest cellular automaton model to investigate the traffic flow, the VDR mechanism is a more
functional one in analyzing the traffic flow (Barlovic et al. 1998), which considers the velocity dependence of random brake \( P \). In this model, due to the variables of discrete time and space, the road is subdivided into cells of length 7.5 m, and the vehicles update their positions and velocities according to the following rules:

1. Acceleration
   
   \( v_n(t) \rightarrow v_n(t + \frac{1}{3}) = \min \{ v_n(t) + 1, V_{\text{max}} \} \)

2. Deceleration
   
   \( v_n(t + \frac{1}{3}) \rightarrow v_n(t + \frac{2}{3}) = \min \{ v_n(t + \frac{1}{3}), d_n(t) \} \)

3. Randomization with probability \( P_n(t+1) \)
   
   \[ P_n(t+1) = \begin{cases} P_o & v_n(t) = 0 \\ P_d & v_n(t) > 0 \end{cases} \]

4. Vehicle motion
   
   \( x_n(t + 1) = x_n(t) + v_n(t + 1) \)

where \( v_n(t) \) is the speed of the \( n^{\text{th}} \) vehicle at time \( t \); \( V_{\text{max}} \) denotes the maximal velocity of vehicles; \( d_n(t) \) is defined to be the number of empty cells in front of the \( n^{\text{th}} \) vehicle at time \( t \); \( x_n(t) \) is the location of the \( n^{\text{th}} \) vehicle at time \( t \); \( P_o \) and \( P_d \) denote the probabilities of randomization according to vehicle’s velocity at time \( t \); \( P_d \) is smaller than \( P_o \).

2.2 Two-route scenario

The two-route scenario was investigated by Wahle et al. (2000) in which travelers choose one of the two routes according to the feedback information displayed on a variable message sign (VMS), which is located at the entrance of routes (Fig. 1). In the two-route scenario, it is supposed that there are two routes A and B of the same length \( L \).

![Fig. 1 Two-route scenario](image_url)

A new vehicle is generated at the entrance of two routes with a probability \( \lambda_n \) at every time step, and chooses one route actively. If a vehicle enters the desired route, it will be subjected to the rules of VDR model on the route. Conversely, if a new vehicle is unable to enter the desired route, it will come into a queue of the corresponding route to wait for entering the desired route at the next time step. The vehicle will be removed after it reaches the end point of the route. An overall procedure of the model is given as follows. Initially, two routes and VMS are empty, and new vehicles choose route \( l (l \text{ is A or B}) \) randomly. After the vehicles enter the routes, traffic information can be measured and processed. Then, feedback information will be generated and displayed on the VMS at each time step.

As a rule, traffic conditions of one route could be characterized by density, mean velocity, and flux, which are defined as follows:

\[
\rho = \frac{N}{L} \quad (1)
\]

\[
\bar{v} = \frac{\sum_{n=1}^{N} v_n}{N} \quad (2)
\]

\[
f = \bar{v} \rho = \frac{\sum_{n=1}^{N} v_n}{L} \quad (3)
\]

where \( \rho \) represents the traffic density on one route; \( \bar{v} \) represents the mean velocity of all vehicles on one route; \( f \) represents the flux on one route; \( N \) is the vehicle number on one route; \( v_n \) is the speed of the \( n^{\text{th}} \) vehicle on one route.

2.3 Graded-information rules

In order to identify the traffic conditions appropriately, all three relevant parameters (including flux, mean velocity, and density) are to be used. It must be emphasized that the identifying of traffic conditions should be assisted by three parameters together instead of only one of them (Yang et al. 2008). Consequently, Fuzzy C-means clustering algorithm (FCM) can be utilized to judge road conditions by flux, mean velocity, and density.

FCM was initially proposed by Bezdek in 1981 for classifying data points in multi-dimensional space. In fuzzy cluster analysis, the membership is used to signify the cluster extent of every data marker. FCM is a soft cluster method for traffic flow data. When using...
FCM to cluster traffic flow data, we have to standardize the original data with range transform so as to unify its range and dimension firstly. FCM divides \( n \) vectors \( x_i (i = 1, 2, \ldots, n) \) into \( c \) fuzzy groups, and computes clustering center \( v_j (j = 1, 2, \ldots, c) \) of each fuzzy group to minimize objective function of non-similarity. The objective function is Eq. (4):

\[
J(U, V) = \sum_{i=1}^{n} \sum_{j=1}^{c} (u_{ij})^m \| x_i - v_j \|^2
\]

where \( n \) is the number of the data points; \( c \) is the number of clustering groups; \( U \) is a membership matrix; \( V = [v_1, v_2, \ldots, v_c] \) is a clustering center matrix; \( u_{ij} \) is a element of matrix \( U \), which is in row \( i \) and column \( j \), indicating membership of data point \( i \) belonging to clustering center \( j \), \( u_{ij} \in [0, 1] \), and

\[
\sum_{j=1}^{c} u_{ij} = 1 \quad \text{and} \quad \| x_i - v_j \|^2 = \text{the Euclidean distance between clustering center } j \text{ and data point } i; m, \text{ a weighed coefficient, is a parameter that controls algorithm flexibility, } m \in (1, +\infty). \text{ Assuming } m = 1, \text{ FCM is degenerated with hard C-means clustering algorithm. Generally, } m \text{ ranges between 1.5 and 2.5 for traffic flow data soft clustering, and its ideal value is 2 (Pal and Bezdek 1995).}

If above mentioned conditions are met, we can construct the Lagrange multiplier, and then calculate the partial derivative for all the input parameters. The essential conditions minimizing the objective function are both Eqs. (5) and (6):

\[
u_j = \left[ \sum_{i=1}^{n} \frac{d_{ij}^{2m}}{d_{ij}^{m}} \right]^{-1} \quad (5)
\]

\[
v_j = \sum_{i=1}^{n} (u_{ij})^m x_i \quad j \in [1, c] \quad (6)
\]

Thus, the clustering center matrix \( V \), which represents \( c \) kinds of traffic conditions, can be calculated by massive historical traffic flow data (including flux, mean velocity, and density). After obtaining the center of various traffic conditions, we can conclude the real-time graded-information of each route based on the Euclidean distance between the clustering center \( j \) and the real-time traffic flow data on each route. The concluding result about route \( l \) would be displayed on VMS as feedback graded-information \( g_l \), and its value range is from 1 to \( c \). The value 1 denotes the worst route traffic condition, and the value \( c \) denotes the best one.

### 2.4 Route-choice model

After acquiring the feedback graded-information \( g_l \) displayed on VMS, travelers would make route-choices according to the Logit model. In this model, travelers would choose route \( l \) with a probability \( P_l \) as Eq. (7):

\[
P_l = \frac{\exp(-\theta T_l)}{\sum_{i=1}^{n} \exp(-\theta T_i)} \quad (7)
\]

where \( T_l \) is estimated travel time when traveler’s choice is route \( l \), it can be calculated by Eq. (8);

\[
\theta \in [0, +\infty) \text{ denotes the rational degree of travelers. When } \theta=0, \text{ the probability of choosing one route is equal to that of another route, and it is 1/2. When } \theta=+\infty, \text{ traveler’s choice is the optimal route.}
\]

\[
T_l = \frac{L}{g_l} \quad (8)
\]

### 2.5 Processing procedure

Figure 2 shows a schematic diagram of the graded-information feedback strategy, which demonstrates the affecting mechanism of information feedback.

![Fig. 2 Schematic diagram of GIFS](image)

### 3 Simulation results and discussion

In simulations, the length \( L \) is 800 cells; the maximal velocity \( V_{max} \) is set to be 4; the vehicle generated
probability $\lambda_k$ is set to be 0.7. In the VDR model, the randomization break probabilities are both $P_0 = 0.5$ and $P_a = 0.25$. In the FCM algorithm, set $m = 2$ and $c \in \{2, 3, 4\}$. In the route-choice model, set $\theta = 0.01$. Before verifying performance of the graded-information feedback strategy, it should fix on the clustering center matrix $V$ by using historical simulation traffic data generated from VDR model. All simulation results are obtained by 25000 iterations excluding the initial 15000 time steps. The graded-information feedback strategy are compared with the travel time feedback strategy under the same condition in order to reveal characters of the new strategy. In addition, we investigated the relationship between the performance and the number of grading, including 2, 3 and 4.

Figure 3 displays the changing of flux of each route according to time when adopting the four different strategies. Both stability and average value are equivalent approximately, because four strategies adopt the identical vehicle generated probability. In other words, the numbers of vehicles passing through the entire two-route system are equal approximately. However, the variation range of TTFS is larger than that of the other three, and the variation range of GIFS with four grades is smaller than that of others.

Figure 4 illustrates the changing of mean speed of each route according to time when adopting the four different strategies. There are perceptible differences among these strategies. The average speed of TTFS is lower than that of GIFS, and the variation range of TTFS is larger than that of the other three. The lowest speed of TTFS is about 1.8, but that of GIFS is about higher than 2.5.

Figure 5 illustrates the changing of vehicle’s number of each route that represents the density of
route essentially according to time when adopting the four different strategies. The average vehicle number by adopting TTFS is larger than that adopting the rest three strategies. In the meantime, the variation range of TTFS is from about 65 to 125, but other three strategies' variation ranges are no more than 105. It implies that traffic congestion maybe occur when using TTFS. Traffic conditions adopting GIFS are more ideal owing to fewer vehicle numbers on routes. The simulation analysis is demonstrated in Tab. 1.

It is known that travel time is a dominant factor for road users making route-choice. It can be seen clearly from Tab. 1 that the average travel time of TTFS is longer than those adopting graded-information feedback strategies. On the other hand, graded-information feedback strategies could alleviate traffic congestion to some extent. When adopting the graded-information feedback strategies, we can realize traffic assignment better, to alleviate traffic congestion. Overreaction of travelers is pressed effectively, and fluctuation of traffic flow is decreased obviously under graded-information environment. In graded-information feedback strategies, the strategy with four grades is superior to the rest two strategies a little. Thus, it can comprehend that the number of grading has negligible effect on the performance of graded-information feedback strategies.

![Figure 4: Average speed of each route](image-url)
4 Conclusions

It is a challenging job to provide travelers with precise and real-time feedback information because of detecting accuracy and information processing of ATIS. On the other hand, travelers take feedback information only as references to make reasonable route choices. This implies that thorough feedback information is not required.

In this study, a workable and feasible information
feedback approach called the graded-information feedback strategy is proposed. Fuzzy C-means clustering algorithm was utilized to grade traffic flow data; including flux, mean speed, and density. VDR model was adopted to verify the performance of this graded-information feedback strategy. Simulation results show graded-information is more advantageous to route-choices of all travelers. Compared with the travel time feedback strategy, this strategy can reduce travel time of travelers and promote utilization efficiency of road networks palpably. Although the number of grading has negligible effect on the performance of feedback strategies, it is suggested that four or even more grades should be adopted if possible.

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References
Eran, B. E., Robert, I., Yoram, S., 2013a. If only I had taken the other road; regret, risk and reinforced learning in informed route-choice. Transportation, 40: 269-293.