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Optimal Route Selection Method Based on Grey Incidence Analysis

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***Abstract* - One function of an in-vehicle traffic flow guidance system is route planning. Given a set of origin-destination (O/D) pair, there could be many possible routes for a driver. A useful traffic flow guidance system should have the capability to support the driver effectively in deciding on an optimal route to his preference. The objective of this work is to model the driver behavior in the area of route selection. In particular, the research focuses on an optimal route selection function in a typical in-vehicle navigation system or dynamic route guidance (DRG) system. In this paper, we want to emphasize the need to orientate the route selection method on the driver's preference. Each feasible route has a set of attributes. Based on the improved AHP and grey incidence analysis, an adaptive optimal route selection method to a driver's preference is proposed, and the corresponding decision support system is also developed, which paves for the development of the traffic flow guidance system.**

Index Terms* − *optimal route selection; grey incidence analysis; AHP; driver's preference; decision support system

I. INTRODUCTION

To a driver, one of the basic problems is route selection. Many factors, such as travel distance, travel time, degree of congestion (number of cars on the road, queue length), toll, degree of difficulty of travel (width of the road, number of lanes, and number of pedestrians and bicycles on the road, etc.) and scenery can influence drivers when they select routes. As the complication of traffic condition, the help of travel experience to drivers is more and more limited. Drivers have to select routes by means of traffic flow guidance system, which is a routing system that provides instructions to drivers based upon "optimal" route solutions.

The issue of driver behavior in terms of route choice and response to guidance is complex. As mentioned in [1], studies have revealed that people's preferences for various route characteristics do vary, and variables can be related to the characteristics of the drivers, their trips, and the routes to which they have been exposed.

So far, the idea of "optimal" has been taken in a very limited sense. Most route guidance systems nowadays compute the "best" route for the driver based on either the shortest time [2], [3] or the shortest distance [4]. Some systems would provide information on congestion of the road as well [5]. Hence, the route selection function makes use of distance data (static) and information on average travel speed (dynamic). Therefore, it can be observed that a routing algorithm that can accommodate the various route selection criteria and their trade-off would be highly desirable.

Many researchers used fuzzy logic, fuzzy set and approximate reasoning to deal with the problem [6]-[9]. Teodorovic and Kikuchi first used fuzzy logic methodology in route selection [6]. They have looked at the problem of route choice between two alternate routes. The driver's perceived travel time on each route is treated as a fuzzy number, and his choice of route is based on an approximate reasoning model and fuzzy inference. The model consists of rules that indicate the degree of preference for each route given the approximate travel time of the two routes. The approach considers only the travel time criterion and cannot be easily generalized to multiple routes. Lotan and Koutsopoulos [7] have also proposed a modelling framework for route choice based on the driver's perception of attributes of the network, attractiveness of alternate routes as well as models for reaction to information. Such an approach works for a paticular O/D set and does not seem general enough for different O/D pairs. Also, for an O/D pair, the inclusion of an additional feasible route means an entirely new set of fuzzy rules. Teodorovic and Kalic [8] have considered route choice problem in air transportation using fuzzy logic. Other than travel time, the approach can handle additional route selection criteria such as travel costs, flight frequency, and the number of stopovers. However, the method works well when there are only two possible routes from the origin to the destination. Any extension such as having a third route would mean the development of an entirely different and carefully designed rule base. Pang, etc. [9] have used a fuzzy-neural (FN) approach to represent the correlation of the attributes with the driver's route selection. Based on a training of the FN network on the driver's choice, the route selection function can be made adaptive to the decision making of the driver. However, the approach needs many input-output pairs to train the FN network.

As mentioned above, route selection is a complex system problem. Traffic information that we can collect is incomplete, and some driver's preference is hard to describe. So the problem of route selection is a grey problem. At the same time, route selection can also be looked as comprehensive evaluation on multi- routes. Based on Evaluation values, we can rank the routes and then select the most desirable one (i.e., optimal route). In this paper, various attributes are fully considered. Based on grey incidence analysis [10] and improved AHP [11], an adaptive optimal route selection method to a driver's preference for traffic flow guidance system is proposed.

II. CONSTRUCT THE INDEX SYSTEM OF ROUTE EVALUATION

It is perceived that a driver may select a route based on many different factors which include: travel distance, travel time, degree of congestion (number of cars on the road, queue length), toll (of expressway or highway), degree of difficulty of travel (width of the road, number of lanes, and number of pedestrians and bicycles on the road, etc.) and scenery (especially for long-distance trip). According to this, a route evaluation index system is established (see fig. 1).

III. CONFIRM THE WEIGHTS OF INDICES

A. Relative importance of indices (i.e., driver's preference)

It is perceived that in some situations, a driver may have a particular preference. The following panel (see fig. 2) can be used as an interface for the driver to specify the relative importance of the route attributes.

B. Confirm the weights of indices

According to driver's preference information, the weights of indices can be determined. If the driver's preference information is "Don't care", then the weight of corresponding index is zero. Other weights of indices can be determined by using the improved AHP, i.e., (-2,2) EM method [11]. The method uses five scales (i.e., (-2,-1,0,1,2)) to judge the relative importance between two elements. At first, a matrix C is obtained by using driver's preference information. Then C is transformed into judgment matrix B. Finally, maximum latent root $\lambda_{\max}$ and eigenvector ω are solved by the method of eigenvector method (EM).

The detailed process is as below:

1) To the evaluation index set $G=\{G_1,G_2,\cdots G_m\}$, *we can obtain matrix C by comparing each two indices:*

$$C=\begin{bmatrix} c_{11} & c_{12} & \cdots & c_{1m} \\ c_{21} & c_{22} & \cdots & c_{2m} \\ \vdots & \vdots & \vdots & \vdots \\ c_{m1} & c_{m2} & \cdots & c_{mm} \end{bmatrix}$$

Where
$$c_{ij}=\begin{cases} 2 & \text{the ith element is insentively or extremely important than the jth} \\ 1 & \text{the ith element is slightly or obviously important than the jth} \\ 0 & \text{the ith element is as important as the jth} \\ -1 & \text{the jth element is slightly or obviously important than the ith} \\ -2 & \text{the jth element is insentively or extremely important than the ith} \end{cases}$$

and $c_{ii}=0$.

Based on above principles, driver's preference information matrix can be transformed into judgment matrix:

	not important	normal	important
not important	0	−1	−2
normal	1	0	−1
important	2	1	0

2) Calculate the importance exponents of indices

We can calculate the importance exponents of indices by using the following equation:

$$r_i=\sum_{j=1}^{m} c_{ij} \quad (i=1,2\cdots,m) \tag{1}$$

3) Obtain the elements of judgment matrix B by the following equation

$$b_{ij}=\begin{cases} r_i-r_j+1 & r_i\ge r_j \\ \left[r_j-r_i+1\right]^{-1} & r_i<r_j \end{cases} \tag{2}$$

Then we can obtain judgment matrix

$$B=\begin{bmatrix} b_{11} & b_{12} & \cdots & b_{1m} \\ b_{21} & b_{22} & \cdots & b_{2m} \\ \vdots & \vdots & \vdots & \vdots \\ b_{m1} & b_{m2} & \cdots & b_{mm} \end{bmatrix}$$

4) Obtain maximum latent root $\lambda_{\max}$ *of matrix B and weight vector* $\omega=(\omega_1,\omega_2\cdots\omega_m)$. Where $\sum_{i=1}^{m}\omega_i=1$, $\omega_i>0$.

IV. OPTIMAL ROUTE SELECTION METHOD BASED ON GREY INCIDENCE ANALYSIS

Suppose the sequence number of evaluation index is i, $i=1,2,\cdots m$, $I=\{1,2,\cdots m\}$, and the index set is $G=\{G_1,G_2,\cdots G_m\}$; sequence number of feasible route evaluated is k, $k=1,2,\cdots p$, $K=\{1,2,\cdots,p\}$. Then d_{ki} ($k\in K, i\in I$) denotes the evaluation information of the *i*-th index of *k*-th route. The grey incidence decision-making method to select the optimal route can be described as:

A. Normalize the original information matrix

Let $D=(d_{ki})_{p\times m}$ denote evaluation information matrix of feasible route k, which can be obtained from the control center of traffic flow guidance system.

In general, indices can be fallen into three sorts, namely, "larger-the-better", "smaller-the-better", and "nominal-the-better". In this paper, indices involved are only the two former sorts, that is

1)If the index is "larger- the- better", we can use upper effect measurement, and the normalized elements are denoted as $\delta_{ki}=d_{ki}/\max_k d_{ki}$.

2)If the index is "smaller -the better", we can use lower effect measurement, and the normalized elements are denoted as $\delta_{ki}=\min_k d_{ki}/d_{ki}$.

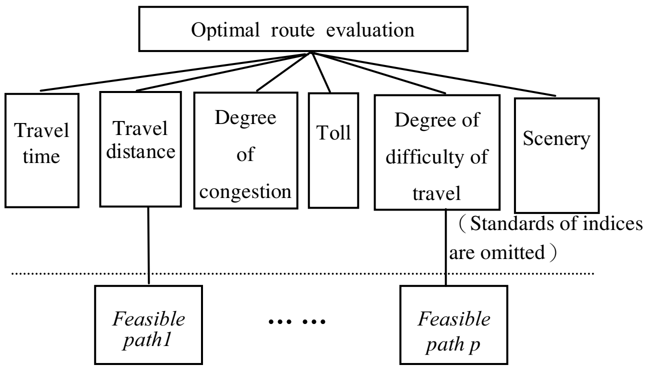

Fig.1 Route evaluation index system

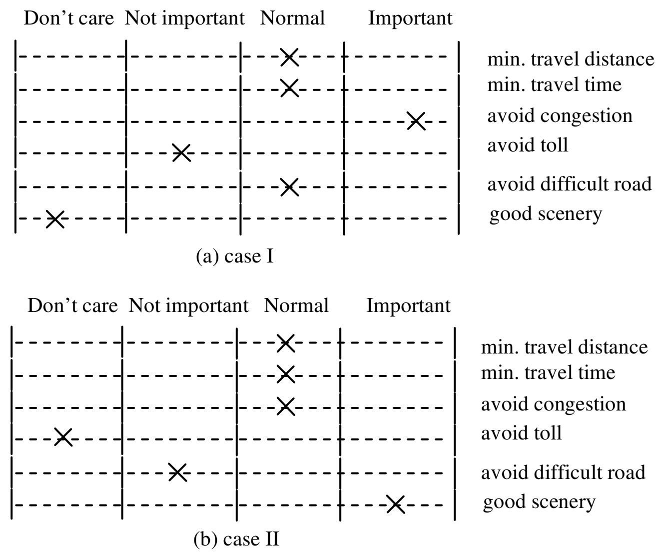

Fig.2 Touch screen for driver's preference selection

After normalizing the original information matrix, we can obtain the normalized information matrix $\delta=(\delta_{ki})_{p\times m}$.

B. Confirm the ideal route

Once the original data are normalized, indices in matrix δ are all positive, namely, larger-the-better. Therefore, $\delta_0=\left\{\delta_{0i}=\max\limits_{k}\delta_{ki}\,\middle|\, i=1,2,\cdots,m\right\}$ is confirmed as the ideal route.

C. Calculate the grey incidence coefficients between the feasible routes and the ideal route

To the index G_i, the grey incidence coefficient between the feasible route k and the ideal route $\xi_k(i)$ can be calculated by using the following equation:

$$\xi_k(i)=\frac{\underset{k}{Min}\,\underset{i}{Min}\,\Delta_{ki}+\rho\,\underset{k}{Max}\,\underset{i}{Max}\,\Delta_{ki}}{\Delta_{ki}+\rho\,\underset{i}{Max}\,\underset{k}{Max}\,\Delta_{ki}} \tag{3}$$

Where $\Delta_{ki}=\left|\delta_{0i}-\delta_{ki}\right|$ （$k=1,2,\cdots,p$；$i=,2,\cdots,\ m$）, and ρ is called as the distinguished coefficient which can be adjusted to help make better distinction between the normalized reference series and normalized comparative series. ρ is taken between 0 and 1.0, and taken as 0.5 in this paper. Then the grey incidence coefficient matrix E between the feasible route k and the ideal route is obtained:

$$E=\begin{bmatrix}\xi_1(1) & \xi_1(2) & \cdots & \xi_1(m)\\ \xi_2(1) & \xi_2(2) & \cdots & \xi_2(m)\\ \cdots & \cdots & \cdots & \cdots\\ \xi_p(1) & \xi_p(2) & \cdots & \xi_p(m)\end{bmatrix}$$

D. Calculate general weighted length and weighted grey incidence grades between the feasible routes and the ideal route

If the evaluated route is ideal route, then $\xi_k(i)=1$;

Otherwise, the correlative degree between the k-th route and the ideal route can be expressed by using general weighted length as followed:

$$d_{k0}=\left[\left[\sum_{i=1}^{m}\omega_i\left|1-\xi_k(i)\right|\right]^q\right]^{1/q} \tag{4}$$

Where q is distance parameter that is integer. In this paper, q=2, is Euclid distance.

Then the weighted grey incidence grade between the feasible route k and the ideal route can be defined as $r_k=1-d_{k0}$ ($k=1,2,\cdots,p$).

To route set K, there is incidence grade vector $R=(r_1,\ r_2,\cdots,\ r_p)$.

E. Comprehensive evaluation and ranking

By ranking r_k $(k=1,2,\cdots,\ p)$, the grey incidence sequence is obtained. If there is $\gamma_o=\max\limits_{1\le k\le p}\{\gamma_k\}$, then the *o-th* route is the optimal route.

According to the mentioned above, the flowchart of a grey incidence analysis-based decision making approach to optimal route selection is shown as fig. 3.

V. ILLUSTRATIVE EXAMPLES

Supposing there are five feasible routes, we use the proposed approach to select the optimal route in two cases.

The normalized information matrix of five feasible routes is as followed:

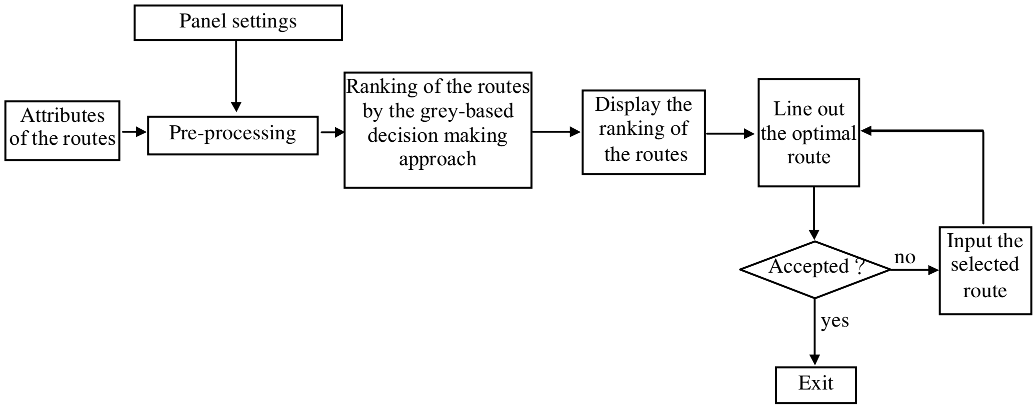

Fig.3 Flowchart of decision support for driver's route selecting

	distance	*time*	*congestion*	*toll*	*difficulty*	*scenery*
route 1	0.8	1.0	0.7	0.4	0.7	0.4
route 2	1.0	0.7	0.5	0.6	0.8	0.5
route 3	0.7	0.8	0.9	0.8	1.0	0.7
route 4	0.6	0.7	1.0	0.6	0.9	0.6
route 5	0.4	0.5	0.8	1.0	0.9	1.0

A. *Case I*

The preference information given by a driver is shown as fig2.(a), from which we can find the driver is very much concerned with avoiding congestion. By using the above method, weight vector $\omega = (0.144, 0.144, 0.527, 0.041, 0.144, 0)$ is obtained, and the weighted grey incidence grades of five routes are r_1 =0.5789, r_2 =0.5176, r_3 =0.7223, r_4 =0.7865, r_5=0.5667, respectively. That is, $r_4 > r_3 > r_1 > r_5 > r_2$. Then the ranking of the routes is route4, route3, routh1, routh5, routh2, and route4 is the optimal route.

B. *Case II*

If the preference information is changed by the driver, which is shown as fig.2(b). The driver is more concerned with good scenery. Then weight vector can be modified as $\omega = (0.144, 0.144, 0.144, 0, 0.041, 0.527)$, and the weighted grey incidence grades of five routes are changed into r_1 =0.4968, r_2 =0.4938, r_3 =0.5709, r_4 =0.5353, r_5 =0.7456, respectively. That is, $r_5 > r_3 > r_4 > r_1 > r_2$. Then the ranking of the routes is route4, route3, routh1, routh5, routh2, and route5 is the optimal route.

The results accord with the practice.

VI. CONCLUSIONS

One function of an in-vehicle traffic flow guidance system is route planning. Given a set of OD pairs, there could be many feasible routes for a driver. A useful traffic flow guidance system should have the capability to support the driver effectively in deciding on an optimal route to his preference. In this paper, an optimal route selection method to a driver's preference is proposed. The main contributions of this paper are as follows:

1) Based on grey incidence analysis theory and improved AHP, an optimal route selection method to a driver's preference for in-vehicle navigation system is proposed. The method has following characters:

a) By using the driver's preference, it can simulate the driver's behavior character of decision-making.

b) Based on the driver's preference, it can rank the feasible routes or give the recommendation of the optimal route.

c) Weights of indices can be adjusted adaptively based on the inputs of drivers.

d) The method is easy to realize.

2) The method proposed in this paper has been developed into computer program, which can be used as a module in in-vehicle traffic flow guidance system.

In conclusion, the method proposed in this paper can satisfy various drives' special preferences, and provide the optimal route for drivers rapidly and correctly, which paves for the development of the intelligent traffic flow guidance system.

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