Proceedings of the
2007 IEEE Intelligent Vehicles Symposium
Istanbul, Turkey, June 13-15, 2007

Optimal Route Selection in Highway Network Based on Travel Decision Making

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Abstract—**Optimal route searching is the research core of navigation system. Nowadays, static searching methods are accepted widely in engineering practices, and the optimal route is virtually the shortest route in some sense. In laboratory environment, the realizing method of optimal route was researched. This paper presents "User-System" decision making theory of optimal route searching with multi goals in highway network GIS. Based on AHP theory, this paper presents the indices system of link impedance evaluation, and the standardized processing method of indices. Based on the evaluation results of Comprehensive Link Impedance, the "Optimal Route Problem" can be transformed into "Shortest Path Problem". Searching with Dijkstra algorithm, the result would show the optimal route which can reflect all influencing factors and can satisfy the user's demands. Through building a testing system with stand-alone computer, the theory raised in this paper was proved to be feasible.**

I. INTRODUCTION

There are many factors that influencing drivers to choose their route, such as travel distance, travel fee, safety, landscape along the route, etc. The existing route searching or inquiring systems are built mainly aimed at urban roadway system, and their concept of "optimal" is parochial, meaning "shortest time" or "shortest distance" generally. For highway route, the absolute single-goal shortest route can not satisfy the user's demand [1]. Furthermore, driver's characters of optimal route choosing are complex, the criterions of route choosing for different drivers are variable [2]. Hence, from the point of travelers' view, all influencing factors and user's initiative should be considered during the process of optimal route selection.

Real-time dynamic route guidance is the ideal solution which is concerned by worldwide researchers [3]. However, the continuous efforts should be made in the engineering practices due to its existing problems [4], especially for the highway network. From the point of view of current research results and applications, static searching of optimal route is the most suitable solution for the engineering application [4]. For the realizing of static optimal route choosing, previous studies have been developed based on gray system theory, fuzzy theory, etc., but most of them were contributed to the urban road network [2]-[5].

Highway traffic is different from urban road traffic in many aspects including travel influencing factors, traffic flow characters, etc. However, few papers focus on the application research of optimal route searching for highway network. The determination of traffic impedance is the core of optimal route searching. Based on the analysis of highway traffic characters, this paper presents a new method of optimal route selection for highway network. Through the determination of highway Comprehensive Link Impedance, this paper presents "user-system" decision-making model to determine the optimal route.

II. BASIC ANALYSIS

A. Abstract of Highway Network

The highway network refers to high-level in this paper, including national highways, provincial highways and county highways. Based on the characters of highway traffic [6], and to simplify the research problem, the highway network is abstracted in Geographic Information System (GIS) as following:

--Highway network is abstracted as digraph with weights, viz. the intersections and highway sections in real highway network are abstracted as nodes and links in the digraph respectively.

--No travel control and delays at nodes, viz. the delays and impedances at nodes are not calculated.

--All links support two-way traffic, and the influencing factors included in the impedance function are consistent in two directions.

--Car is adopted as the standard vehicle [7].

B. Analysis of Decision-making Model

In the user-machine interactive environment of optimal

Manuscript received January 14, 2007. This work was supported in part by the Communication Department of Jiangsu Province, China, under Grant 04X015.

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route searching in highway GIS, the realizing mode of comprehensive link impedance determines the searching mechanism of optimal route. Based on the analysis of the realizing process of comprehensive link impedance, decision-making models can be classified into user model, system model, and user-system model [6]. "User-System" model was adopted in this paper which is shown in Fig.1. This model not only comprised user's needs, but also reduces the influences of too many indices on user's decision-making, so as to prove the veracity of decision-making.

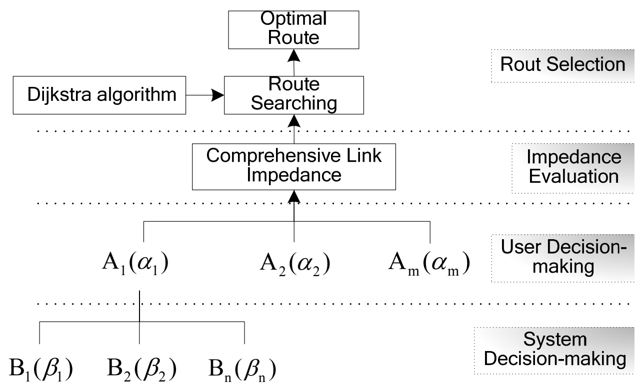

Fig. 1. User-System Decision-making Model

Where: A_i(i=1,2,…,m)--Evaluation indices of link impedance in rule layer, viz. link impedance with single goal; α_i (i=1,2,…,m)--The weights of indices in rule layer determined by user; B_i (i=1,2,…,n)-- The value of indices; β_i (i=1,2,…,n)--The weights of indices in index layer determined by system.

III. Determination of Comprehensive Link Impedance

According to "user-system" decision-making model, the evaluation indices system of comprehensive link impedance is established that is suitable to the whole highway network. Thus, the problem of optimal route choosing with multi goals should be transformed to the problem of shortest path [1].

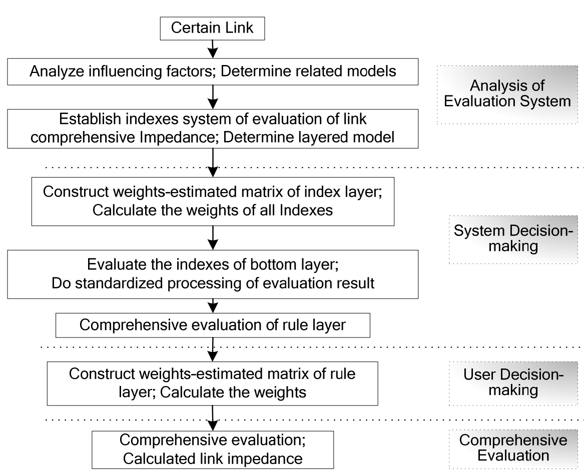

Fig. 2. Flowchart of Evaluation of Link Comprehensive Impedance

A. Evaluation Process of Comprehensive Link Impedance

The evaluation of Comprehensive Link Impedance is based on the theory of Analysis Hierarchy Process (AHP) [8]. The evaluation process is shown in Fig. 2.

B. Establishment of Indices System of Comprehensive Link Impedance

On the basis of the principles of indices selecting [8], the evaluation indices system of comprehensive link impedance is established which is shown in Fig. 3. This indices system is not step-up layered model strictly: for "Comfort and Safety" rule, it formes strict indices system independently; but for "Travel Time" and "Travel Fee" rules, this paper adopted certain models to evaluate them.[4].

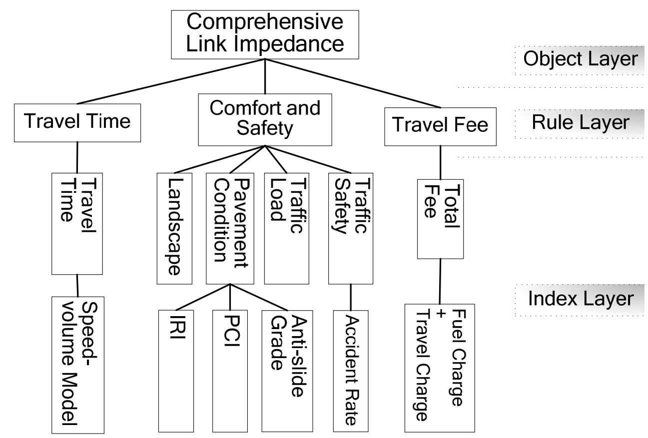

Fig. 3. Indices System of Link Comprehensive Impedance

C. System Decision-making

Based on AHP theory, the quantitative consistency process for all indices is discussed. Furthermore, the weights of indices are determined. Accordingly, the comprehensive evaluation of link impedance in "rule layer" is presented.

1) Quantificational Expression of Indices in Bottom Layer

The indices in bottom layer can be classified into qualitative indices and quantificational indices generally, shown in Table 1. The qualitative indices include "Anti-slide Grade" and "Landscape", described by grade; the dimensions of quantificational indices are different. The detailed descriptions are shown in Table 1, and reference [4] had discussed the methodology in details.

2) Quantitative Consistency Process of Indices

-- *Qualitative indices*: Use the method of rank graded with weights, to transform the rank into standardized value [6].

-- *Quantificational indices*: The indices could be classified into direct ratio and inverse ratio indices, which can be processed with standardized formula as following [6]:

For the indices in "Comfort and safety" layer:

$$\mu(x_i) = \begin{cases} \mu(x_i)^* / \lambda_{\max} & \text{when}\mu(x_i)^* \text{more bigger more better} \\ \lambda_{\min} / \mu(x_i)^* & \text{when}\mu(x_i)^* \text{more smaller more better} \end{cases} \quad (1)$$

Where: $\mu(x_i)$ -- The value of index x_i after consistency process; $\mu(x_i)^*$ -- The initial value of index x_i ; $\lambda_{\max}$, $\lambda_{\min}$ -- Contrastive value of index x_i , and in this paper use the extremum of relevant indices of all links in the highway network. The value of each index $\mu(x_i)^*$ is bigger than zero without exception, viz. $\lambda_{\max} > 0$, $\mu(x_i)^* > 0$. Hence, the above standardized formula is feasible.

For the indices in "Travel Time" and "Travel Fee" layers:

$$\eta(x_i) = \eta(x_i)^* / \gamma_{\max} \qquad i = 1,2 \tag{2}$$

Where: $\eta(x_i)$ --The value of index x_i after consistency process; $\eta(x_i)^*$ -- The initial value of index x_i ; $\gamma_{\max}$ --The maximum of relevant indices of all links in the highway network. The values of each index, $\gamma_{\max} > 0$ exists all the time. Therefore, the above standardized formula is feasible.

3) Weights Determination of Indices

On the ground of AHP theory and based on the survey results of 50 travelers, the weights of indices were calculated using "Latent Root Methodology". The results are listed in Table 1.

TABLE 1
WEIGHTS TABLE OF INTEGRATED EVALUATION OF LINK IMPEDANCE

Evaluation Rule	Indices and Weights		Composite Weights	Measurement of Indices
Travel Time ϖ_1	Travel Time 1		1	Hour
Travel Fee ϖ_2	Total Fee 1	Travel Charge	1	Yuan(￥)/ vehicle
		Fuel Charge		Liter/km· unit price
Comfort and Safety ϖ_3	Traffic Load 0.164		0.164	V/C value
	Pavement Conditions 0.2478	IRI 0.534	0.177	RQI value
		PCI 0.267	0.089	PCI value
		Anti-slide Grade 0.199	0.066	Excellent, Good, Fair, Poor, Serious
	Traffic Safety 0.464	Accident rate 1	0.464	AH value (times/ hundred million.km)
	Landscape 0.040		0.040	Excellent, Good, Fair, Poor, Serious

4) Evaluation of Link Impedance with Single Goal

For "Travel Time" and "Travel Fee" rules, the results of Standardized processing of indices are their evaluation results. As to "Comfort and Safety" rule, it's evaluated using linearity weighted summation method [8],[9]. However, the evaluation is confronted with a problem that the value trends of the three indices in rule layer are not consistent. Relative to the Comprehensive Link Impedance, the standardized values of indices in "Travel Time" and "Travel Fee" layers are more better when more smaller, but the standardized values of indices in "Comfort and Safety" rule are reverse. So, considering the consistency of the three indices, the comfort and safety rule needs to be deal with consistency process through following formula:

$$T = 1 - \sum_{i=1}^{m} W^{(i)} \mu(x_i) \tag{3}$$

Where: T --Evaluation result of "Comfort and safety" rule; $W^{(i)}$ --Composite weights of indices relative to rule layer; m--Number of indices needed to be evaluated; $\mu(x_i)$ --Standardized values of indices.

D. User Decision-making

Through the user-machine interactive interface, users can take part in the determination of Comprehensive Link Impedance, shown in Fig.4.

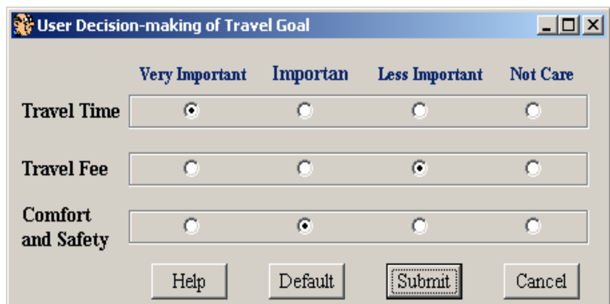

Fig. 4. Setting Interface of User Decision-making

The user's partial information can be processed quantificationally [6],[10] through (-2,2) eigenvector method (EM) which can estimate the relative weightiness of two indices by five features (-2, -1, 0, 1, 2). The main calculation steps include:

1) Construction of comparison matrix C

Based on the user's partial information set in the machine-user interface, shown as Fig.4, the comparison matrix C is obtained.

$$C = \begin{bmatrix} c_{11} & c_{12} & \cdots & c_{1m} \\ c_{21} & c_{22} & \cdots & c_{2m} \\ \vdots & \vdots & \vdots & \vdots \\ c_{m1} & c_{m2} & \cdots & c_{mm} \end{bmatrix} \tag{4}$$

Where:

$$C_{ij} = \begin{cases} 2 & \text{the element i is obviously important compared with element j} \\ 1 & \text{the element i is slightly important compared with element j} \\ 0 & \text{the importance of element i and j is the same} \\ -1 & \text{the element j is slightly important compared with element i} \\ -2 & \text{the element j is obviously important compared with element i} \end{cases}$$

The potential comparison results of travel goals (c_{ij}) are listed in TABLE 2.

TABLE 2
COMPARISON RESULTS OF TRAVEL GOALS (C_{IJ})

i/j	Very Important	Important	Less Important
Very Important	0	1	2
Important	-1	0	1
Less Important	-2	-1	0

2) Calculation of weightiness sort of each travel goal

$$r_i = \sum_{j=1}^{m} c_{ij} \quad (i = 1,2,\cdots,m) \tag{5}$$

3) Construction of matrix B

Based on the above calculation results r_i , the comparison matrix *C* can be transformed into matrix *B*, shown as (6).

$$B = \begin{bmatrix} b_{11} & b_{12} & \cdots & b_{1m} \\ b_{21} & b_{22} & \cdots & b_{2m} \\ \vdots & \vdots & \vdots & \vdots \\ b_{m1} & b_{m2} & \cdots & b_{mm} \end{bmatrix} \tag{6}$$

The element value of matrix *B* can be calculated by following (7).

$$b_{ij} = \begin{cases} r_i - r_j + 1 & r_i \geq r_j \\ \left[r_j - r_i + 1\right]^{-1} & r_i < r_j \end{cases} \tag{7}$$

4) Calculation of weights of travel goals ω_i

The maximum latent root $\lambda_{\max}$ and the relative eigenvector $\omega = (\omega_1, \omega_2, \cdots, \omega_m)^T$ of matrix *B* can be calculated through eigenvector method (EM). Where $\sum_{i=1}^{m} \omega_i = 1, \omega_i > 0$.

Therefore, ω_i is the weight of each travel goal. Hereon, the weight of specified goal is "zero" when user's partial information is "Not Care"; the weight of specified goal is "one" when there's only one travel goal in existence; when using the default setting of system, the optimal route is the "shortest time" route.

E. Evaluation of Link Impedance with Multi-goals

Based on the linearity weighted summation method, the evaluation formula of Comprehensive Link Impedance is established, refer to (8):

$$A = \sum_{i=1}^{2} \eta(x_i) \cdot \varpi_i + T \cdot \varpi_3 \tag{8}$$

where: A -- Evaluation result of Comprehensive Link Impedance (no dimension); $\eta(x_i)$ -- Standardized value of each rule; T -- Evaluation result of comfort and safety rule; ϖ_i -- Weights of each rule determined by user: $i = 1$,Travel Time rule; $i = 2$,Travel Fee rule; $i = 3$,Comfort and Safety rule.

IV. Realization of Optimal Route Selection

Since the comprehensive link impedance does not change in the searching process, the "Optimal Route Problem" can be transformed into "Shortest Path Problem". So, the optimal route searching could be realized based on Dijkstra algorithm, which involves all influencing factors and would satisfy the user's demand.

To prove the feasibility of the theory raised in this paper, based on Tianjin highway network in China and the ArcInfo GIS platform, the authors developed a testing system with stand-alone computer. The development environment is shown as following:

--GIS Platform: ArcInfo8.3;
--Database: Access 2003;
--Development Environment: Visual Basic Applications (VBA), ArcObjects [12];
--Data: Vector electronic map, Attribute Database (Access format).

When developing the testing system, the table of link impedance was established, shown in Fig.5. Four fields were added in addition to the key fields, including "Time", "Cost", "Comfort", "Integration", to storage the calculated results of indices in the rule layer and the calculation results of comprehensive link impedance. "Integration" field is dynamic to storage the evaluation result of Comprehensive Link Impedance according to the user's setting through user-machine interactive interface. Using "Integration" field value as the static link impedance, and searching the shortest route based on the Dijkstra algorithm, then the result should be the optimal route with multi goals for certain user.

ID	Link Code	Initial Milepoint	End Milepoint	Time	Cost	Comfort	Intergration
1	G020120111001	0	.37	.0061	.0068	.358	.10
2	G020120111002	.37	12.247	.196	.2171	.456	.27
3	G020120223001	12.247	12.648	.0066	.0073	.395	.11
4	G020120223004	12.648	52.045	.65	.72	.682	.
5	G020120223005	52.045	52.32	.0045	.005	.715	.20

Fig. 5. Attribute Table of Link Impedance

Fig. 6 shows the example searching result of optimal route under the user configuration shown in Fig. 4. The result shows that the optimal route differs from the shortest path clearly.

V. Conclusion

For the optimal route selection of highway network, static mode is more suitable for the engineering practices. The cores of optimal route searching are the determination of link

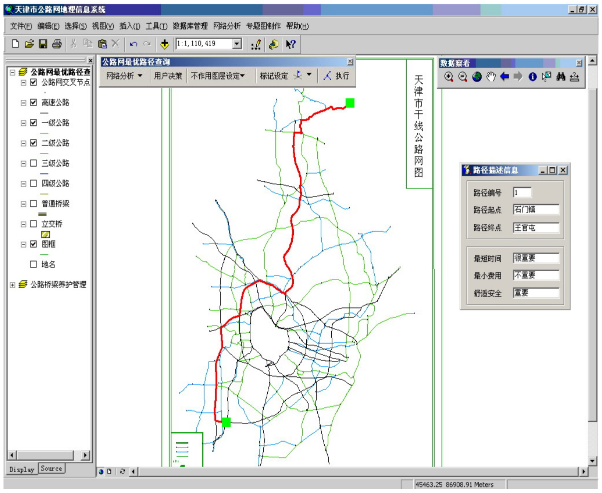

Fig. 6. Result of optimal route searching

impedance and realization of searching algorithm. The link impedance determines the accuracy of optimal route. Based on "user-system" decision-making model, the evaluation theory of comprehensive link impedance with user concerned is presented. And a testing system was established to prove the feasibility of the theory. The results indicate that the theory presented in this paper shows strong feasibility in practice.

The theory of optimal route searching presented in this paper is on the elementary research stage, and it was predigested properly. More influencing factors should be considered in future such as differences of regions, vehicle class, period of travel time, intersection impedance, and etc. By considering these factors, it's hoped to build more actual highway network model, thus to improve the reliability and applicability of optimal route searching. Furthermore, the feasibility of applying the theory presented in this paper to the vehicle navigation system should be given a in-depth study.

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