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Grey Relational Analysis for Route Choice Decision-making under Uncertain Information

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Abstract

The purpose of this work is to present a route choice decision-making method under uncertainty conditions, and to explain the route choice behavior process from behavior point of view. A method of grey relational analysis is presented to handle route choice decision-making problem, using interval number vectors of route attributes and incomplete attribute weights vectors. The influence factors of route choice are analyzed firstly. Then giving the interval values of each route attributes, the grey relational coefficient of each route alternative from positive ideal solution (PIS) and negative ideal solution (NIS) are calculated, and an optimal model is provided in order to get the suitable attribute weights vector. Furthermore, all alternative routes are ranked according to the rate values. In the end, a numerical example is given with the real network of 3 lanes and 7 alleys in Fuzhou, and the results show that the proposed method is simple and effective.

Keywords: *Route choice; Multi-attributes; Grey relational analysis; Interval numbers*

1. Introduction

Route choice modeling is essential to traffic management, especially to dynamic route guidance. Modeling route choice behavior is given the possibility to forecast traveler's behavior, to assess traveler's perceptions of route characteristics and to predict the further traffic states in transportation network. Route choice decision-making is an evaluation system that reflects the assessment and perception of travelers with respect to the route alternatives attribute. How to select a best route for a traveler to get to his/her destination, his/her travel experience and sources of route information are the most important factors.

In the literature, three approaches have frequently been applied in route choice: expected utility theory or random utility theory [1-3], prospect theory or cumulative prospect theory [4-7], and multi-attribute decision making theory [8]. Some combined models were also presented to evaluate route choice behavior [9]. In the last decade, more and more studies have sought to simulate the route choice process with multi-attribute decision model. Lam et al. [10] constructed a route choice model in road networks, which takes departure time, travel distance, parking position, stop time as route attributes, and a route choice behavior with multi-criteria in stochastic, time-varying networks is analyzed in [11]. Turan et al. [12] presented a hybrid model for handling fuzzy perceptions in route choice, which combine fuzzy logic and analytical hierarchy process (AHP) to describe route choice decision-making. Sitarz [13] proposed a model for multi-criteria dynamic route programming with ant algorithms and simulated annealing. An optimal routing model was presented in stochastic time-dependent networks with ant algorithms by CHEN et al. [14], which also put forward a framework for optimal routing policy

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problems. Most of the above theories are based on the assumption that travelers have perfect knowledge about the route information, but it is well known that route choice behavior is complex, which is characterized by the unavailability of exact information about traveler's preferences, the lack of traveler's knowledge about the network composition and the uncertainty about traveler's perceptions of route characteristics.

The purpose of this paper is to provide new insight into the traveler's route choice behavior with multi-attribute decision making. It is well known that traveler decisions are affected by many subjective and objective factors, which has characteristics of the imprecise and vague values of traveler's perception. Unfortunately, most of existing techniques for quantitative analysis take an absolute value for route choice behavior in the real traffic network. This study therefore develops a general route choice behavior based on multi-attributes decision making with interval number, which will be identical to the choice behavior in the real world. It is hoped that the proposed method may be applied in further research into route choice behavior of traffic networks under uncertainty environment.

The rest of the paper is organized as follows. Section 2 explains the influence factors for selecting his/her best route among his/her choice set. Section 3 describes the detailed analysis of the route choice process with multi-attributes decision making. An illustrative example is given in section 4 to show the process of traveler's route choice behavior. Finally, the conclusion and suggestions for future research of route choice behavior are given in section 5.

2. Influence Factors of Route Choice

In the literature, the influence factors of route choice decision making can be divided into two categories. One is the subjective factors which take the traveler's judgments into account, including the travel experiment, personal preference and income level of every traveler. The other one is objective factors, which reflect the characteristics of route alternative. The objective factors contain travel time, travel distance, the degree of traffic congestion, the number of intersection, etc., which was discussed in detail by Turan et al. [12]. Liu et al. discussed the contribution of travel time reliability to dynamic route choice using real-time loop data [15].

There are many factors impact on traveler's route choice decision-making, but in actual travel process, the travel goal is similar, besides minimizing some expectation of travel cost, subjective preference should also meet the traveler's travel behavior. In this paper, traffic congestion, travel time, travel distance and travel time reliability are selected for route attributes, and among four attributes, only travel time reliability is benefit attribute, the others are cost attributes.

3. An Approach for Multi-attribute Decision Making with Interval Numbers

We consider a traffic network with a common origin O and common destination D that is modeled as a directed graph $G=(V(G),E(G))$ with node set $V(G)$ and link set $E(G)$. There are m route alternatives for traveler to choose, and which route is taken by traveler depending on the n attributes of each route alternative. Let $X=\{X_1, X_2, \cdots, X_m\}$ ($m \geq 2$) be a discrete set of route alternatives, $A=\{A_1,\ A_2, \cdots A_n\}$ be the set of route attributes. If the attribute value of the j^{th} index A_j of feasible route alternative X_i is an interval number $[s_{ij}^-, s_{ij}^+]$,

$i = 1,2,\cdots m$, $j = 1,2,\cdots n$, the decision matrix S with index value of interval numbers is constructed as follows,

$$S = \begin{bmatrix} [s_{11}^-, s_{11}^+] & [s_{12}^-, s_{12}^+] & \cdots & [s_{1n}^-, s_{1n}^+] \\ [s_{21}^-, s_{21}^+] & [s_{22}^-, s_{22}^+] & \cdots & [s_{2n}^-, s_{2n}^+] \\ \cdots & \cdots & \cdots & \cdots \\ [s_{m1}^-, s_{m1}^+] & [s_{m1}^-, s_{m1}^+] & \cdots & [s_{mn}^-, s_{mn}^+] \end{bmatrix}$$

(1)

In the following, we introduce the decision making approach based on grey relational analysis to solve the route choice problems.

Step 1. Normalize the original decision matrix S into standardized decision matrix R with equation (2) and equation (3). In general, there are cost attributes and benefit attributes in multi-attribute decision making problems [16]. In order to measure all attributes in dimensionless units and to facilitate inter-attribute comparisons, the above different types of decision making matrix S is normalized into the matrix $R = ([r_{ij}^-, r_{ij}^+])_{m \times n}$, where $r_{ij}^-, r_{ij}^+ \in [0,1]$.

For the cost attributes,

$$\begin{cases} r_{ij}^- = (1/s_{ij}^+) \Big/ \sum_{i=1}^{m} (1/s_{ij}^-) \\ r_{ij}^+ = (1/s_{ij}^-) \Big/ \sum_{i=1}^{m} (1/s_{ij}^+) \end{cases} \quad i = 1,2,\cdots m, j = 1,2,\cdots,n \tag{2}$$

For the benefit attributes,

$$\begin{cases} r_{ij}^- = s_{ij}^- \Big/ \sum_{i=1}^{m} (s_{ij}^+) \\ r_{ij}^+ = s_{ij}^+ \Big/ \sum_{i=1}^{m} (s_{ij}^-) \end{cases} \quad i = 1,2,\cdots m, j = 1,2,\cdots,n \tag{3}$$

Step 2. Determine the positive ideal solution (PIS) and negative ideal solution (NIS) as follows [17],

$$y = [y_j^-, y_j^+] = [\max_i r_{ij}^-, \max_i r_{ij}^+]$$

(4)

$$z = [z_j^-, z_j^+] = [\min_i r_{ij}^-, \min_i r_{ij}^+]$$

(5)

Where y represent the positive ideal solution and z the negative ideal solution.

Step 3. Calculate the grey relational coefficient of each alternative from PIS and NIS using the following equation respectively [18], where $i = 1,2,\cdots m, j = 1,2,\cdots,n$.

$$\xi_{ij}^+ = \frac{\min_i \min_j \left| [y_j^-, y_j^+] - [r_{ij}^- - r_{ij}^+] \right| + \rho \max_i \max_j \left| [y_j^-, y_j^+] - [r_{ij}^- - r_{ij}^+] \right|}{\left| [y_j^-, y_j^+] - [r_{ij}^- - r_{ij}^+] \right| + \rho \max_i \max_j \left| [y_j^-, y_j^+] - [r_{ij}^- - r_{ij}^+] \right|}$$

(6)

$$\xi_{ij}^{-}=\frac{\min_i\min_j\left\|\left[r_{ij}^{-},r_{ij}^{+}\right]-\left[z_j^{-}-z_j^{+}\right]\right\|+\rho\max_i\max_j\left\|\left[r_{ij}^{-},r_{ij}^{+}\right]-\left[z_j^{-}-z_j^{+}\right]\right\|}{\left\|\left[r_{ij}^{-},r_{ij}^{+}\right]-\left[z_j^{-}-z_j^{+}\right]\right\|+\rho\max_i\max_j\left\|\left[r_{ij}^{-},r_{ij}^{+}\right]-\left[z_j^{-}-z_j^{+}\right]\right\|}$$

(7)

In the above two equations, the distance of interval number is Defined as follows:

$$\left\|\left[y_j^{-},y_j^{+}\right]-\left[r_{ij}^{-}-r_{ij}^{+}\right]\right\|=\sqrt{\left(y_j^{-}-r_{ij}^{-}\right)^2+\left(y_j^{+}-r_{ij}^{+}\right)^2}$$

(8)

$$\left\|\left[r_{ij}^{-},r_{ij}^{+}\right]-\left[z_j^{-}-z_j^{+}\right]\right\|=\sqrt{\left(r_{ij}^{-}-z_j^{-}\right)^2+\left(r_{ij}^{+}-z_j^{+}\right)^2}$$

(9)

Where $\rho\in[0,1]$ is the identification coefficient and $\rho=0.5$ is used in this paper.

Step 4. Construct the formula of the grey relation degree of each route alternative from PIS and NIS,

$$\xi_i^{+}=\sum_{j=1}^{n}\xi_{ij}^{+}w_j \quad , \quad i=1,2,\cdots m,\ j=1,2,\cdots,n$$

(10)

$$\xi_i^{-}=\sum_{j=1}^{n}\xi_{ij}^{-}w_j \quad , \quad i=1,2,\cdots m,\ j=1,2,\cdots,n$$

(11)

Step 5. Determine the suitable attribute weight vector. In order to calculate the grey relation degree ξ_i^{+} and ξ_i^{-}, the weight vector w_j must be pre-determined, so the following multi-objective optimization model is formulated,

$$\begin{cases}\max\xi_i^{+}=\sum_{j=1}^{n}\xi_{ij}^{+}w_j, & i=1,2,\cdots,m\\ \min\xi_i^{-}=\sum_{j=1}^{n}\xi_{ij}^{-}w_j, & i=1,2,\cdots,m\\ s.t.\quad w_j\geq 0,\sum_{j=1}^{n}w_j=1,\ j=1,2,\cdots,n\end{cases}$$

(12)

If traveler choose route behavior with non-preference, the above multi-objective optimization model can be translated into a single objective optimization model,

$$\begin{cases}\min D=\sum_{i=1}^{m}\sum_{j=1}^{n}\left(\xi_{ij}^{-}-\xi_{ij}^{+}\right)\\ s.t.\quad w_j\geq 0,\sum_{j=1}^{n}w_j=1,\ j=1,2,\cdots,n\end{cases}$$

(13)

The weight vector w_j can be calculated according the equation (13).

Step 6. Calculate the rate value of each route alternative from PIS using the following formulation,

$$K_i=\xi_i^{+}/(\xi_i^{+}+\xi_i^{-}),\quad i=1,2,\cdots,m$$

(14)

Rank the original route alternative with the calculated rate values. The larger the K_i value is the better the alternative will be, and we denote $K_i \succ K_j$ if K_i is better than K_j in this paper.

Normalizing the above rate value by following equation, we get the percentage of traveler selecting route i.

$$\varphi_i = K_i \Big/ \sum_{i=1}^{m} K_i , \quad i = 1,2,\cdots,m$$

(15)

4. Case Study

In this paper, three lanes and seven alleys, a real traffic network located at the center of Fuzhou city was taken as case study (As shown in Fig.1). There are three routes for traveler to choose from origin O to destination D, that is route 1: ①→②→⑥→⑦; route 2: ①→③→④→⑦; route 3: ①→③→④→⑤→⑥→⑦.

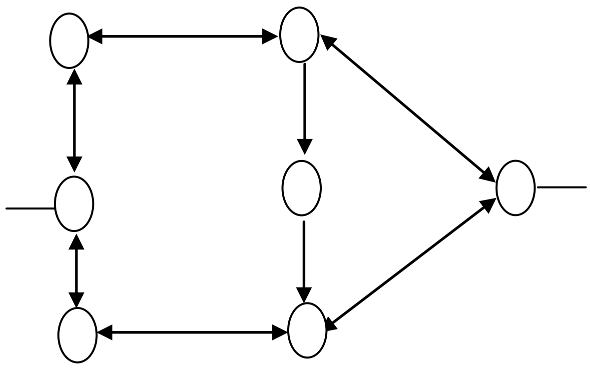

Figure 1. A Real Traffic Network in Fuzhou

Four attributes of route is selected to evaluate the alternatives: (1) the degree of traffic congestions A_1, (2) travel time A_2, (3) travel distance A_3, (4) travel time reliability A_4, and among four attributes, only A_4 is benefit attribute. Suppose the index value of each attribute is interval number, which is given by some professional experts according to the intensity of attribute with number from 1 to 9. Take the attribute the degree of traffic congestion A_1 for example, 1 represents that the traffic state is the most unblocked, and 9 expresses the most crowded. The original decision matrix of index value was obtained as follows:

$$S = \begin{bmatrix} [3,6] & [4,7] & [4,6] & [6,8] \\ [4,7] & [4,6] & [4,5] & [5,7] \\ [5,8] & [5,9] & [5,7] & [3,6] \end{bmatrix}$$

Utilize equation (2) and equation (3) to normalize the above original decision matrix S into standardized decision matrix R as follows.

$$R = \begin{bmatrix} [0.213,0.767] & [0.204,0.594] & [0.238,0.491] & [0.286,0.571] \\ [0.182,0.575] & [0.238,0.594] & [0.286,0.491] & [0.238,0.500] \\ [0.160,0.491] & [0.159,0.491] & [0.204,0.393] & [0.143,0.429] \end{bmatrix}$$

If the information about the attribute weights is uncertain, giving the attribute weights that is subject to the following equations:

$$0.7w_2 \le w_1 \le 0.9w_2 \,,\, w_1 + w_3 \le 0.5 \,,\, w_3 + w_4 \le w_1 + w_2 \,,\, w_4 \le 0.2 \,,\, \sum_{j=1}^{4} w_j = 1$$

Calculate the positive ideal solution with equation (4):

$$y = ([0.213,0.767][0.238,0.594][0.286,0.491][0.286,0.571])$$

Calculate the negative ideal solution with equation (5):

$$z = ([0.160,0.491][0.159,0.491][0.204,0.393][0.143,0.429])$$

Calculate the grey relational coefficient of each route alternative from PIS and NIS using equation (6) and equation (7),

$$\xi_{ij}^{+} = \begin{bmatrix} 1 & 0.806 & 0.746 & 1 \\ 0.420 & 1 & 1 & 0.622 \\ 0.334 & 0.521 & 0.525 & 0.412 \end{bmatrix}, \quad \xi_{ij}^{-} = \begin{bmatrix} 0.334 & 0.556 & 0.576 & 0.412 \\ 0.619 & 0.521 & 0.525 & 0.543 \\ 1 & 1 & 1 & 1 \end{bmatrix}$$

Then by the model (13), the following single objective optimization model is established.

$$\begin{cases} \min D = 0.199w_1 + 0.25w_2 + 0.165w_3 + 0.079w_4 \\ s.t. \quad w_j \ge 0, \quad \sum_{j=1}^{4} w_j = 1, \quad w_j \in W \end{cases}$$

Solving the model, we get the route attribute weight vector:

$$w = (0.21, 0.30, 0.29, 0.20)$$

Calculate the grey relation degree of each route alternative from PIS and NIS with equation (10) and equation (11),we get ξ_i^{+} and ξ_i^{-} as follows:

$\xi_1^{+} = 0.868$, $\xi_2^{+} = 0.803$, $\xi_3^{+} = 0.461$, $\xi_1^{-} = 0.486$, $\xi_2^{-} = 0.547$, $\xi_3^{-} = 1.000$

Calculate the rate value of each route alternative from PIS using equation (14),

$$K_1 = 0.641,\ K_2 = 0.595,\ K_3 = 0.316$$

According to the rate values of each route alternatives, we rank the route alternatives K_i as: $K_1 \succ K_2 \succ K_3$

And thus, the best route alternative is route 1, i.e., the most number of travelers would like to select route 1 for his/her travel route. Normalizing K_i by equation (15), we got $\varphi_1 = 41.3\%$, $\varphi_2 = 38.3\%$, $\varphi_3 = 20.4\%$.

The used traffic network is a real network located at the center of Fuzhou city, and a SP (stated preference) survey with 150 questionnaires was undertaken simultaneously. The result of survey shows that 69 travelers (46%) select route 1, 53 travelers (35.3%) select route 2, and 28 travelers (18.7%) select route 3. Comparison to the survey results, it is evidence that the proposed decision making model is satisfactory and in agreement with practice.

5. Conclusions

In this paper, a route choice method based on multi-attributes decision making is proposed to handle the uncertainty information in route choice behavior. Giving the attribute value of each route is interval number, and attribute weight vector is not an accurate value but subject to some requirement, which reflects that the route choice decision making is concerning uncertainty. Route choice decision-making process for traveler was explained in a hierarchy structure, then a real traffic network located at the center of Fuzhou city was taken as illustration example, the result indicates the route choice method proposed is in accordance with the behavior of traveler decision-making. Further research directions include the improvement of the suggested method, and the improvement of accuracy of route attributes values which can really reflect the actual state of transportation network.

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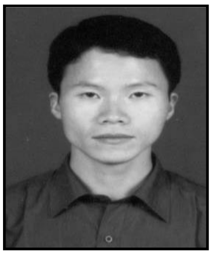

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