An AHP-Fuzzy approach for incorporation of driver’s requirement in route guidance system

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Abstract—Route choice mechanism is the key technology of the route guidance system. This paper focuses on the integration of the analytical hierarchy process (AHP) and fuzzy logic theory to realize the dynamic route guidance system based on the geographic information system (GIS). The AHP-FUZZY approach is a multi-criteria combination system developing the hierarchy structure and adaptively generating the weights based on the two step fuzzy rule system, which can greatly simplify the definition of decision strategy and represent the multiple criteria explicitly. Based on the AHP-FUZZY approach, a simulation system is implemented to compare with the traditional route guidance system and the results are validated.

I. INTRODUCTION

Route planning technique is the key technique of vehicle navigation system providing path planning strategy for the travellers. However, most of route guidance systems usually give the shortest distance path or shortest time path based on the historical average traffic data, it easily causes traffic congestion. Therefore, optimum route choice based on the static and dynamic traffic information can provide optimum path for travellers and alleviate traffic congestion.

In the past few years, much research has been done to study the route choice algorithm, the mainly used algorithms are as follows: fuzzy logic algorithm and genetic algorithm [1], fuzzy neural algorithm [2], fuzzy and analytical hierarchy process (AHP) [3], fuzzy logic-ant colony [4], analytical hierarchy process (AHP) using quantifier-guided ordered weighted averaging (OWA) procedure [5]. The fuzzy logic based system is widely used mainly because of its capacity to handle vague ness and it is also easy to combine with other methods to adaptively choose the optimum route. OWA is a kind of multi-criteria aggregation procedure which was developed in the context of fuzzy set theory [6] and is composed of two weights: the weights of criterion importance and order weights. The order weights decide the optimum route choice of road network, while the AHP proposed by Saaty (1980) is based on the additive weighting model. The route choice can be given by two step method. First, the AHP decomposes the decision problem into a hierarchy of subproblems composed of several criterions and the importance of weights is associated with their criterions. Then the weights can be aggregated with the criterions by the weighted combination methods. This approach is of great importance for spatial decision problems that can not complete pair wise comparisons of the alternatives [7, 8].

However, due to the vagueness and uncertainty of traffic attributes and route decisions, a crisp, pair-wise comparison of AHP can not capture the vagueness of traffic attributes. Thus, fuzzy logic is introduced into the AHP structure to compensate the deficiency of AHP. In addition, the above mentioned approaches are mainly based on provision of O/D pairs’ routes without considering heavy traffic congestion of some road segments, and the optimum route given by the comparison of the O/D pairs is similar. Thus, having a entirely different route considering both the traffic density of road segments of each intersection and the overall cost of O/D pairs is of great importance to the extension of route choice problems.

This paper is outlined as follows: section II gives a description on some important attributes of a route. Section III presents the AHP approach integrated with fuzzy rules. Section IV presents an implementation of the approach and the results analysis. Some conclusions are given in Section V.

II. TRAFFIC INFORMATION DESCRIPTION

Traditionally, the movements of vehicles are considered as isolated moving units in the route guidance system. However, a car driving on the road is influenced by the whole road network including static and dynamic information. The traffic flow model has been considered a vivid model to represent the movement of vehicles driving on the road network. For the road traffic information, several attributes can describe the road traffic, such as: the road segment number, lane number, road segment length, traffic capacity, density, speed and travel time, where traffic capacity Q is assumed known and can be collected in the traffic information centre, the vehicle density ρ and the speed V are important road attributes to describe road load capacity and passability, while the average speed plays more important role in the whole journey than the instantaneous speed. The average speed can be decided by the average time of vehicles on the road segment and the traffic density can be calculated by the traffic flow model: ρ = Q/V. Generally, distance and travel time are usually considered as the main factors to decide the route selection neglecting the traffic density which can represent the traffic load capacity and the intensity of travellers’ comfort. Basically, travellers usually want to get to their destination at least cost. Thus, there are three main criteria considered in this route guidance system, as follows:

Road segment distance: it is the Euclidean Distance of each road segment;
Traffic density: it can be decided by the traffic flow model.
Travel time: it is determined by road segment length, traffic capacity and so on, and the travel time function can be represented by the following link congestion function developed by the Bureau of Public Roads (BPR) [9]:

\[
T_a(v_a) = t_a \left[ 1 + \alpha \left( \frac{V_a}{C_a} \right)^\beta \right]
\]

\(t_a\): it is free flow travel time on link a per unit of time;
\(V_a\): it is volume of traffic on link a per unit of time on the road segment a;
Consider a directed graph $G = (V, E)$ with an origin point $o \in V$ and a destination $d \in V$. $A$ is denoted to be the set of all acyclic routes from the origin point $o$ to destination point $d$ on $\tilde{G} = (V, E)$. For each road segment of road network $e \in E$, criteria is defined, then the multi-criteria structure is imposed on the road network.
As mentioned above, the purpose of this paper is to give the least cost route decision considering both the traffic density of road segments of each intersection and the overall cost of O/D pairs. Supposing that there are a set of m alternatives, that is, m adjacency road segments for each node, which can be denoted by \( A_i \) for \( i = 1, 2, ..., m \). The alternatives are to be evaluated by a set of p objectives \( O_q \), where \( q = 1, 2, ..., p \). The objectives are measured in terms of the underlying attributes. Thus, a set of \( n \) attributes associated with the \( p \) objectives can be denoted by \( C_j \), where \( j = 1, 2, ..., n \). While a subset of attributes associated with the \( q \)th objective is denoted by \( C_{k(q)} \), for \( k = 1, 2, ..., l; l \leq n \). There are two sets of weights, \( w = [w_1, w_2, ..., w_p] \) and \( w(q) = [w_{1(q)}, w_{2(q)}, ..., w_{l(q)}] \) are assigned to the objectives and attributes, respectively. The weights have the following properties: \( w_q \in [0, 1] \), \( \sum_{q=1}^{p} w_q = 1 \), and \( w_{k(q)} \in [0, 1] \), \( \sum_{k=1}^{l} w_{k(q)} = 1 \). Based on the basic knowledge of AHP approach, the fuzzy logic approach is employed to improve its performance. For the weights of the objectives and weights, they are not constant values any more, which will be decided by the fuzzy logic rules. Combining with the above weights, the global weights of each criterion, \( w^g_i \), are calculated as follows:

\[
R_i = \sum_{j=1}^{n} w^g_i x_{ij}.
\]

The fuzzy rule system employed in the AHP approach can be described as follows:

1) For the weights of the objectives, they are adaptively adjusted by the first fuzzy rule system.

In this proposed hierarchical structure, the objective is to decide the objectives’ values and weights, and finally generate the final route choice decision. As mentioned on Section II, the road attributes, which can influence the route choice decision, are length, travel time and traffic density. It is assumed that all drivers want to get to their destination based on the least cost. The travelling cost composed of travel distance and travel time, is influenced by the traffic on the roads. For different time periods, the traffic is greatly different, thus, the cost of the road segment is also different from different time period of day. However, the cost of road segment is greatly influenced by the road load capacity, that is, traffic density, thus, the fuzzy rules can be given according to the intensity of traffic density. The first fuzzy rules are described as follows:

a. If the traffic density is low, then the weight of distance is high, that is, the time weight is low (For the free traffic flow, the cost of traffic is totally decided by the shortest path.).

b. If the traffic density is high, then the weight of time is high, that is, the distance weight is low (For time periods of traffic congestion, the cost of traffic is totally decided by the least time path).

c. If the traffic density is medium, then the weight of distance is medium, that is, the time weight is medium. As to the value of the weights, it can be generated by the fuzzy membership function and defuzzification process.

2) For the criterion weights \( w_{k(q)} \), they are generated by the second fuzzy rule system.

Pairwise comparisons are the key technology of AHP approach which involves above mentioned three steps. However, in order to alleviate heavy traffic congestion on some road segments, it needs a rule to consider the intensity of traffic density of the road segment in the overall road network and the intensity of traffic density in the adjacency edges. In this paper, a fuzzy rule based pair-wise comparison is proposed, which involves two-step approach.

a. For the crisp input, it involves the normalized criterion value \( x_{ij} \), which can vividly show the intensity importance of road segment in the total road network. In order to represent the intensity of importance of each adjacency edge’ cost, another crisp input is the road segment’s relative density which can be determined by the pair-wise comparisons of adjacency lists. In addition, the weights of travel time and distance objectives are influenced by the absolute density of the road segments. Thus, there are three crisp inputs to determine the weights of travel time and distance, respectively. For the density objective, it is just influenced by the absolute and relative density of each road segment.

b. After determining the crisp inputs for each attributes, the key technology is to determine the fuzzy rules for fuzzy system. For each crisp input of the fuzzy system, if each of them is classified into three levels, the maximum of the fuzzy rules are 27 fuzzy rules to determine the weights of travel time and distance. It can combine with the first fuzzy system to diminish the number of fuzzy rules. As mentioned above, there are three rules involved in the fuzzy rule system. In fact, these three rules can be modified for two extreme situations and one normal situation. For the former two fuzzy rules, they can specially be used for the two extreme situations, that is, shortest path situation when the density is rather low and least time situation when the density is extreme large. For the third fuzzy rules in the fuzzy system, if the density is medium, it will combine with the second fuzzy system to generate the new fuzzy rules. That is, for the second fuzzy system, it has a precondition that the traffic density is medium. Thus, there will be maximum 9 fuzzy rules for distance and travel time attributes. Based on the fuzzy rules and the membership functions of fuzzy sets, the criterion weights \( w_{k(q)} \) are generated by the defuzzification process. The final evaluation results of the \( i \)th alternative can also be calculated as follows:

\[
R_i = \sum_{j=1}^{n} w^g_i x_{ij}, \text{ where } x_{ij} \text{ is associated with the attributes value.}
\]

The implementation process of the AHP-FUZZY system is as follows:

1) For the hierarchical structure of AHP-FUZZY system, the goal is to achieve the least cost route choice, which can be decomposed into three objectives associated with three traffic situation based on the traffic density, such
as: shortest path, least time and least cost. The attributes associated with each objective are distance, travel time and density, and their weights can be determined by the two fuzzy rule systems. The map layers contain the attributes values assigned to road segment, and the standardized criterion values are denoted as follows: \( X = [x_{ij}]_{m \times n} \); for \( x_{ij} \in [0,1], j = 1,2, \ldots, m \).

2) Determining the crisp inputs for the two fuzzy systems: For the first fuzzy system, \( w_q \) are generated for the weight of qth objective. As to the second fuzzy system, it has a precondition that the density is medium, then the fuzzy based pairwise comparison system will determine the criterion weights \( w_k(q) \).

3) The final evaluation cost of the ith alternative can also be calculated as follows: \( R_i = \sum_{j=1}^{n} w_i^j x_{ij} \), where \( x_{ij} \) is associated with the attributes value. After determining all the cost of road segment, it can make use of the Dijkstra’s algorithm to realize the least cost calculation.

IV. RESULTS ANALYSIS

1. Data collection and analysis

The traffic data used in this paper is four weeks traffic volume data collected on the main roads in Sydney from 15th Aug to 11th Sep in 2005. The road network contains 287 nodes and 592 directed edges. For this study, it just considers the weekday traffic condition, because it has similar traffic characters. For the real time traffic prediction, four weeks traffic volume data is separated into two parts, the first part of which is used as historical data or training data and the second part of which is used as predicted data. First, this paper uses the former three weeks traffic volume data to be the training data or historical data to get the real time traffic prediction model. Secondly, it uses the fourth week traffic data as the predicted data. Because fifteen minutes traffic data is collected, that is, there are 96 time intervals each day and 1440 time intervals totally for 15 days’ historic traffic data.

In this paper, the real time route guidance system is realized based on the embedded Google Maps, which can make use of the geography information of Google company and traffic information.

According to the graph theory, it needs to know the vertex and edge information to realize path planning. For the form of vertex, it stores the vertex number and the position coordinate and the edge information includes the directed the identity of road segment, road lanes \( N \), length \( L \) and traffic volume \( Q \), where the length can be calculated by the sphere distance.

2. Results analysis

The path planning algorithm is to find optimal path from the origin to destination based on the graph theory. In the graph theory, an effective data structure needed to be established to represent the edges and vertices of the graph. In this paper, adjacency list is used to represent the directed graph instead of the traditional adjacency matrix. For a graph with a sparse adjacency matrix, the main advantage of adjacency list is that an adjacency list occupy less space, because it does not use any space to represent edge that are not present. In addition, adjacency list facilitate the path planning operation. Because there is no need to find all vertices of the data structure, it just needs to read its adjacency list.

For the off-peak hours, the traffic is usually free flow traffic and the AHP-FUZZY approach usually chooses the shortest path for the travellers. During the peak hours, for the different road segments, they have different traffic density, thus the cost weights of road segment are different from each other. If the AHP-FUZZY approach can adaptively find the optimum path during the peak hours, this approach can be validated well. In order to validate this implementation, we choose the one of the O/D pairs (from A to B) and the least cost path is compared with the shortest path and least time path. The results for three route choice methods are shown in Table 1 and the paths for three route choice methods at 8:10am is shown in Fig 2. From Table 1, it shows that different paths are given for different route choice methods during the whole day. For the off-peak hours, similar paths are given which have similar distance and time, while, during the peak hours, the shortest distance path has the longest distance, while the least cost path has the medium distance and medium time. From Fig 2, it shows that the difference of optimum path is that the shortest distance path takes the Southern Cross Drive, while the least time path takes the M4 Western Distributor Freeway. From the Fig3 and Fig4, it shows that traffic volume on Southern Cross Drive and M4 Western Distributor Freeway are higher than the average traffic volume on other road segments. Especially for M4 Western Distributor Freeway, the forecast of traffic data at 8:10 am shows that there is heavy traffic congestion. Based on the study of traffic data on routes of shortest distance path and least time path, it can be shown that the least cost path is more optimum and it can also balance the traffic flow on the roads without betray the cost requirements.

<table>
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<tr>
<th>Route choice methods</th>
<th>Shortest distance</th>
<th>Least time</th>
<th>Least cost</th>
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<td>Time</td>
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V. CONCLUSION

In this paper, a AHP-FUZZY approach for route guidance system is proposed in which the final route choice is always based on the least cost for different time periods of day. Compared with the traditional route choice approach, this proposed paper calculates the least cost based on the combination of road segments’ cost, rather than the route selection among a number of known routes. In addition, for the two step fuzzy rule system, the former one can adaptively adjust the optimum model among shortest path, least time and least cost for different road segment and different time periods of day, and the latter one makes use of membership function to adjust the weights of criterions considering the intensity of importance of criterion values and the intensity of importance of road segment in the adjacency list. The simulation experiment has been done on the road network in Sydney. The simulation results show that this AHP-FUZZY approach can adaptively adjust the weights of the objectives to get the least cost path for the different time periods of day.

REFERENCES