Application of Fuzzy Optimal Path Algorithm for Bus Route Expansion in Thai Nguyen City

Thi Mai Thuong Duong¹, Huy Nguyen Phuong² and Thu May Duong³

¹, ³ Department of Computer Science, University of Information and Communication Technology, Thai Nguyen, Vietnam.
² Department of Electronics Engineering, Thai Nguyen University of Technology, Thai Nguyen, Vietnam.

¹ duongmaithuongcntt@gmail.com, ² nguyenphuonghuy@tnut.edu.vn, ³ thumay.cntt@gmail.com

ABSTRACT
One frequently encountered problem in building and applying Geographical Information Systems (GIS) is to find the optimal path (shortest path). Bus route expansion is one demonstration example. The essence of this problem is the implementation of two options. The first is selecting potential locations for bus stop, and the other is choosing one optimal route which go through some potential locations with “lowest cost”. In the past, the problem of finding the optimal path in GIS will be implemented under hard computing. However, geographical data are inherently inaccurate and imprecise. Therefore, a fuzzy logic approach will make the solution to the problem of optimal path becomes more flexible. In this paper, the authors present four steps to expand bus routes in Thai Nguyen city of Vietnam in which using the fuzzy optimal path algorithm. It includes map database collection, map overlay (to identify potential locations), data fuzzification and applying the fuzzy optimal path algorithm.

Keywords: Geographic Information System, Bus Route Expansion, Fuzzy Shortest Path, Fuzzy Optimal Path Algorithm.

1. INTRODUCTION
Development of public transport bus services is a compelling need of Thai Nguyen city to meet the travel needs of the people, to avoid traffic congestion, to reduce pollution and to ensure traffic safety. Therefore, the city should have suitable strategy and schedule in developing appropriate public transport bus service, attracting people to change from traveling by personal vehicles (especially motorcycles) to public transportation and completing appropriate bus transport network. Currently, due to the need to travel by bus of the people is increasing, bus routes are overloaded. Some places have not yet deployed bus services. Therefore, It is necessary to expand some new bus routes.

The essence of bus route expansion problem is the implementation of two options. The first is selecting potential locations for bus stop between the starting point and the end point, and the other is choosing one optimal route which go through some potential locations with “lowest cost”. In the opinion of experts, the design should ensure the following requirements:

(1) The new bus route selection should be based on the analysis of the current status of bus transport network to ensure better services.
(2) Bus stops should be placed adjacent to public centers such as banks, offices, schools, hospitals, stations…
(3) The bus stop should be placed in areas with high population density
(4) Bus routes that have partial overlap must choose same bus stops
(5) Distance between two adjacent bus stops on a bus route should be reasonable option (for example, for urban routes, the maximum distance is 1.5 km and a minimum of 500 m)

Currently, in the world, so many GISs have been completely built with the ability to store, manage, access, process, analysis and provide necessary information to implement decisions in many fields of public service [1]. Therefore, the use of GIS for the problem of expanding bus routes in the city of Thai Nguyen is a reasonable choice. To perform this task, in addition to common data processing techniques in GIS, the application of algorithms to find the shortest path or optimal path is necessary[2]. We absolutely can apply these algorithms under hard computing. However, we will encounter some difficulties as follows:

(1) GIS can not accurately determine the absolute optimal location to place bus stops. On the other hand, during
the construction of bus stops in real life, we may encounter some obstacles in people's houses, trees, land clearance and compensation ... so bus stops can be shifted in the range up to hundred meters. These bus stops shifting will lead to shifting of the other bus stops and affect the global results. There are even cases that we have to recalculate.

(2) The handling of GIS data that accepts these incorrect factors is very difficult for traditional (hard computing) algorithms of optimal path.

Based on the above analysis, this article presents four steps to expand bus routes in Thai Nguyen city of Vietnam in which using fuzzy optimal path algorithm. It includes map database collection (to determine the necessary attributes of map data), map overlay (to identify potential locations), data fuzzification (to solve the problem according to the fuzzy logic approach) and applying the fuzzy optimal path algorithm (to find the optimal bus route). These four steps are illustrated on (Fig. 1)

2. MAP DATABASE COLLECTION

The purpose of this step is to collect the necessary attributes of map data that correspond to the first four criteria as described in the Introduction. So we need to collect map data containing the relevant attributes such as spatial, population, traffic, administrative offices, old bus stops ... This work has been done with the help of ArcMap module in ArcGIS software. The result of this step is in order to create the shape file of the data as traffic.shp, administrative_office.shp, population.shp and old_bus_stops.shp ... (Fig. 2)

3. MAP OVERLAY (SHAPEFILES)

Each shapefile that was obtained in the above step describes only one or a small number of attributes of the map according to spatial data. Thus, in order to detecting points so that contain full attributes required for placing bus stops (such as: near crowded residential areas, near public places or administrative offices, a priority bus stations available...), we need to overlay all shapefiles collected in the map database collection step. The results are shown in Fig. 3. Positions that have been marked in red x symbol are potential locations to place bus stops.

4. DATA FUZZIFICATION

To solve the problem of finding the optimal path according to the fuzzy logic approach, we must fuzzify crisp data (crisp locations). From the potential locations for the construction of bus stations which have received in map overlay step, we do the data fuzzification step. In fact, there are many complex criteria for fuzzification such as distance, population density, implementation costs. In this paper, we just illustrate the distance fuzzification.

As mentioned above, the placement of a bus stop on the map can be shifted away due to many different causes. Therefore, the location of a bus stop will be fuzzified in two dimensions (x and y) by triangular fuzzy numbers. The tip of a triangle is a crisp potential location, two points on the left and right are based on allowed deviation of position in two dimensions (Fig. 4). After fuzzification, data are saved to the point.mat file.
The next step, we shall determine the cost between two points. In fact, this cost depends on many economic and social aspects. In terms of distance aspect, we can represent the fuzzy distance between two fuzzy points \( A\{x_a, x_b, x_c\}, B\{y_a, y_b, y_c\} \) on a bus route in triangular fuzzy numbers \( AB(A_B, B_A, AB) \). This step is shown in Fig. 5.

Where: \( AB_u = \sqrt{(x_b - x_h)^2 + (x_h - x_b)^2} \) (crisp distance between A and B)

\( AB_u \) and \( AB_c \) are maximum deviation of position in both x,y dimensions.

If A and B are not on the same road, the distance AB is infinity. After calculating the entire distance between the points with the ability to set the bus stops, data are saved to the distance.mat file.

5. APPLYING THE FUZZY OPTIMAL ALGORITHM

Up to now, in the world, a lot of fuzzy shortest path algorithms are proposed. These algorithms are based on fuzzy number of distance. For example, the FSA algorithm (proposed by Petrik [3]), the algorithm of finding the best path based on fuzzy numbers by Kiran Yadav [4], the fuzzy Dijkstra algorithm by Yong Deng [5].

In this paper, the key idea of the fuzzy optimal path algorithm is to represent the distance between two bus stop locations by a triangular fuzzy number and then applying the fuzzy Dijkstra algorithm.

A triangular fuzzy number A can be defined as \( A = (a, b, c) \) where the membership can be determined as follows and shown in Fig. 6

\[
A(x) = \begin{cases} 
0 & \text{if } x \leq b - a \\
\frac{x - (b - a)}{a} & \text{if } b - a < x < b \\
1 & \text{if } x = b \\
\frac{(b + c) - x}{c} & \text{if } b < x < b + c \\
0 & \text{if } x \geq b + c 
\end{cases}
\]  

(1)

\[
P(A) = \frac{1}{6}(a_1 + 4b_1 + c_1) 
\]  

(2)

The representation of the canonical representation of the addition operation \( \oplus \) on triangular fuzzy numbers A and B can be defined as:

\[
P(S) = P(A \oplus B) = \frac{1}{6}(a_1 + 4b_1 + c_1) + \frac{1}{6}(a_2 + 4b_2 + c_2)
\]  

(3)
end while;
Return dist[];
end fuzzy_optimal_path

The results obtained after applying the algorithm is a new bus route with the best suited bus stop locations. Based on this optimal route, we carried out final adjustment stages in two steps:

- Dispose of the potential bus stops obtained from the step of map overlay but not on the optimal route
- Remove some bus stops on the route to meet the 5th criteria in requirements for bus stop design as mentioned in the introduction

Table 1: Result after running the algorithm to find the optimal path

<table>
<thead>
<tr>
<th>ID</th>
<th>Source</th>
<th>Destination</th>
<th>Distance (km)</th>
<th>No. bus stop (Before adjustment)</th>
<th>No. bus stop (After adjustment)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Tan Long subdistrict</td>
<td>NI town</td>
<td>39.8</td>
<td>40</td>
<td>25</td>
</tr>
<tr>
<td>2</td>
<td>Gang Thep town</td>
<td>Yen Lang district</td>
<td>33.6</td>
<td>34</td>
<td>23</td>
</tr>
<tr>
<td>3</td>
<td>Thai Market</td>
<td>Ky Phu</td>
<td>36.6</td>
<td>17</td>
<td>14</td>
</tr>
<tr>
<td>4</td>
<td>Dong Hy district</td>
<td>Song Cong town</td>
<td>39</td>
<td>33</td>
<td>27</td>
</tr>
<tr>
<td>5</td>
<td>Tan Long subdistrict</td>
<td>Phu Binh district</td>
<td>31.5</td>
<td>32</td>
<td>24</td>
</tr>
<tr>
<td>6</td>
<td>Thai Market</td>
<td>Dinh Hoa district</td>
<td>52.9</td>
<td>42</td>
<td>22</td>
</tr>
<tr>
<td>7</td>
<td>Quyet Thang subdistrict</td>
<td>Dinh Ca town</td>
<td>44.8</td>
<td>39</td>
<td>21</td>
</tr>
<tr>
<td>8</td>
<td>Song Cong town</td>
<td>Trai Cau subdistrict</td>
<td>42.8</td>
<td>31</td>
<td>17</td>
</tr>
<tr>
<td>9</td>
<td>Thinh Dan subdistrict</td>
<td>Quan Chu subdistrict</td>
<td>27.6</td>
<td>24</td>
<td>12</td>
</tr>
<tr>
<td>10</td>
<td>Thai Nguyễn station</td>
<td>Coc lake</td>
<td>17</td>
<td>28</td>
<td>15</td>
</tr>
</tbody>
</table>

Table 1 shows the results obtained when applying the fuzzy optimal algorithm to expand 10 bus routes in Thai Nguyen city of Vietnam. In which, results of the 10th row is illustrated in Figures 8 and Figures 9.
Fig. 8 shows the expansion bus route with the starting point is the center station of Thai Nguyen city and the end point is the Coc lake (a famous tourist destination of the city). This bus routes will provide very good conditions for tourists from other areas. After applying the fuzzy optimal algorithm, we obtain the optimal route with 17 km long passing through 28 potential bus stops. After adjustment, we get the new bus route with 15 bus stops.

6. CONCLUSIONS

In this paper, the authors present main steps to apply the fuzzy optimal path algorithm to bus route expansion problem in Thai Nguyen city of Vietnam. At first, we collected GIS data with attributes that meet the requirements for a bus stop such as population, traffic, administrative offices, old bus stops. Then we overlaid obtained maps to identify potential points that are suitable for bus stops. After identifying these crisp potential locations, we carried out determine fuzzy cost (distance) between two potential locations by a triangular fuzzy number. Finally, depending on the source and destination of the new bus route, we obtained the optimal route according fuzzy optimal path algorithm. Results show that the algorithm works well and can be applied in the real world.

7. ACKNOWLEDGMENTS

This research was supported by a grant for the university research from the ICTU (University of Information and Communication Technology), under project # T2016-07-13. We thank our colleagues from the ICTU who provided insight and expertise that greatly assisted the research. We would also like to show our gratitude to the TNUT (Thai Nguyen University of Technology) which partially supported for the research.

REFERENCES