DEVELOPMENT OF HANOI BUS INFORMATION SYSTEM

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ABSTRACT. Public transport is a part of the contemporary urban model. In Vietnam, the bus system is re-established a few years ago. At the same time, some maps have been published for helping the bus passengers. But these maps are still lacked of rich contents and useful functionalities.

With the aim to improving the effectiveness of Hanoi public transport system, the authors have applied GIS technology for developing an information system of Hanoi bus. A logical model of the bus network consisting of 2 sub-networks and 5 cost attributes has been designed. This model serves as a basis for developing a bus geodatabase with 5 feature classes. For managing the geodatabase, a set of tools extending the capabilities of ArcGIS software via COM (Component Object Model) interface has been created.

The developed information system has very useful functionalities: supplying information about bus stop and bus lines with illustrated photos, searching for streets and specific objects, finding the fastest path by bus between places in the city,... These functionalities will help the bus passengers, especially those in the city for the first time, to be orientated in the complicated Hanoi bus network.

1. Introduction

The rapid development of Geographic Information System (GIS) technology in the past decade exerts strong influence on many socio-economic fields, including the public transport field. Thus, GIS is widely used for modeling traffic in urban transport network (Goh, 1993; Hossain and McDonald, 1998), for creating a road accident database (Lupton and Bolsdon, 1999) and an expert system supporting public transport management (Mackett and Edwards, 1996). For building enterprise-wide transportation data repository, the Virginia Department of Transportation (VDOT) has developed the so called Unified Network Transportation Data Model (UNETRANS) (Widner and Bucher, 2005). Recently, the Hong Kong's Bus Company established their own bus information system based on ArcGIS technology (Baumann, 2004). Moreover, the governments of the world largest cities (Paris, Seoul,...) also maintain electronic maps of their public transport systems.

Hanoi - the capital and the second largest city of Vietnam - is experiencing difficulty in solving public transport problems for many years. Recently, with the help of the European Union, the City has partly resolved this problem by re-establishing the public bus system. Today, the Hanoi bus system has 55 lines and serves over million passengers daily. The large number of bus lines, along with the maze-like street

1 These maps are available at addresses http://www.ratp.info/orienter/cv_cv_en/cartebus.php, and http://bus.congnamul.com/SeoulRouteWebApp/view_english/map.jsp...
system in the center area of Hanoi, can make headache for passengers, even if they are the native Hanoians. Some efforts for helping passengers to be orientated in the complicated bus network was made by Hanoi Transportation Corporation (Transerco) in publishing an electronic map of Hanoi bus system\(^2\), but this map is still lacking of many useful information, for example, the detailed information about bus stops, or travel time, etc.

Being aware of problems of Hanoi bus passengers, the authors has conducted research on creation of logical and physical models of a bus network, and on this basis developed an information system of Hanoi bus (HBIS) by using ArcGIS software.

2. The network dataset concept

According to ESRI (Environmental Systems Research Institute Inc.) (ESRI, 2005a and 2005b), a network in general consists of: network elements, network attributes, and network connectivity.

Network elements are the main components that make a network dataset. There are 3 kinds of network elements: edges, junctions, and turns. Edges are elements that connect to other elements (junctions) and are the links over which resources flow. Junctions connect edges and facilitate navigation from one edge to another. Turn elements record information about movement between two or more edges.

Connectivity in a network dataset is based on geometric coincidences of line endpoints, line vertices, and points and applying connectivity rules that was set as properties of the network dataset. Connectivity in ArcGIS begins with the definition of connectivity groups. A network element of one connectivity group can only connect to others elements that belong to the same group. Each edge source is assigned to exactly one connectivity group and each junction source can be assigned to one or more connectivity groups. Junctions that are assigned to two or more connectivity groups are the only way that edges in different connectivity groups can connect. Edges in the same connectivity group can be made to connect in two ways, set by the connectivity policy on the edge source. If the "Endpoint" policy is set then line features become edges joining only at coincident endpoints. Otherwise, if "Any vertex" connectivity policy is set then line features are split into multiple edges at coincident vertices.

Network attributes are properties of the network elements that control traversability over the network. They have four basic properties: name, usage type, units, and data type. The usage property specifies how the attribute will be used during analyses, which is identified as either a cost, descriptor, restriction, or hierarchy. Cost attributes are used to measure and model impedances, such as travel

\(^2\) This map is available at address http://basao.com.vn/map/VN_DOLMap/home_giaothong.asp.
time (e.g. transit time on a street) or demand (e.g. the volume of garbage picked up on a street). Descriptors are attributes that describe characteristics of the network or its elements. Restrictions are attributes for identifying "restricted" elements that cannot be traversed. The last type of network attributes is hierarchy, which means the order or grade assigned to network elements.

3. Logical model of a bus network

In practice, if a bus passenger wants to travel from place A to place B, he (she) has to do as follows:

(1) Walk from A to the nearest bus stop;
(2) Wait for an appropriate bus;
(3) Take the bus and ride to a stop near place B;
(4) Get off the bus;
(5) Walk to the destination place B.

Thus, the total time \( T \) needed to get from A to B is defined as:

\[
T = t_1 + t_2 + t_3 + t_4 + t_5 = \sum_{i=1}^{5} t_i ,
\]

where:

- \( t_1 \) is time needed for walking along streets from A to the nearest bus stop. This time is estimated by dividing the distance to average walking speed (about 4 km/h).
- \( t_2 \) is waiting time for an appropriate bus. The passenger may get the bus immediately or he may wait by maximum the interval between two consecutive buses of the same line. Therefore, the average value of \( t_2 \) is a half of this interval.
- \( t_3 \) is time taken to ride from get-on to get-off bus stop. This time parameter is determined experimentally.
- \( t_4 \) is time to get off the bus, it can be assumed to be equal zero.
- \( t_5 \) is time to walk along streets from the get-off bus stop to the destination place B. This time is estimated similarly to \( t_1 \).

It can be seen that for traveling from A to B, the passenger will have 2 types of movement: walking on the streets and riding by bus. Consequently, the logical model of a bus network consists of 2 network groups:

- A network group of bus lines, called "Group 1";
A network group of streets for walking, called "Group 2".

The passenger can get on and get off only at the bus stops. Therefore, the bus stops are junctions that connect the two above network groups (Figure 1).

For modeling get-on and get-off actions, the authors suggest to use the so called "virtual" bus stops: the get-on action is modeled by going from "actual" (physical) to "virtual" bus stop, and vice versa, the get-off action is equivalent to going from "virtual" to "actual" bus stop. Therefore, the "virtual" bus stop can be considered as a bus door. The lines connecting "actual" and "virtual" bus stops are belonging to the bus subnetwork (Group 1).

4. Geodatabase design

The bus network geodatabase is created with a single feature dataset that contains 5 feature classes. The design of these feature classes is shown in Table 1. Based on the first 4 feature classes, a network dataset is built with 2 groups (or subnetworks):

- Group 1 models the bus subnetwork, is built from Bus_Line, Bus_Stop and Virtual_Stop feature classes.

- Group 2 models the street subnetwork, is built from Street and Bus_Stop feature classes.

Thus, the junctions created from Bus_Stop feature class are belonging to both of groups and play role of connecting the bus and the street subnetworks.
Table 1. Feature classes in the bus network database

<table>
<thead>
<tr>
<th>Feature class</th>
<th>Geometry type</th>
<th>Network role</th>
<th>Attributes</th>
<th>Attribute data type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bus_line</td>
<td>Line</td>
<td>Edge</td>
<td>Bus_Number Start_Stop End_Stop Forward_Time_NonPeak Backward_Time_NonPeak Forward_Time_Peak Backward_Time_Peak Get_On_Off Ticket_Price Shape_Length</td>
<td>Integer Text Text Float Float Float Float Integer Float Double</td>
</tr>
<tr>
<td>Street</td>
<td>Line</td>
<td>Edge</td>
<td>Name Walking_Speed Shape_Length</td>
<td>Text Float Double</td>
</tr>
<tr>
<td>Bus_stop</td>
<td>Point</td>
<td>Junction</td>
<td>Name Served_Bus_Lines Address Bus_Stop_Photo Specific_Object_Photo</td>
<td>Text Text Text Text Text</td>
</tr>
<tr>
<td>Virtual_stop</td>
<td>Point</td>
<td>Junction</td>
<td>Name Bus_Line</td>
<td>Text Integer</td>
</tr>
<tr>
<td>Specific_Object</td>
<td>Point</td>
<td>-</td>
<td>Name Address Photo</td>
<td>Text Text Text</td>
</tr>
</tbody>
</table>

For modeling walking and bus traveling time, the system uses 5 cost attributes as shown in Table 2. In this table, the first 4 attributes are time needed for riding by bus from stop to stop along streets. If some of these streets are one-way, for example, only forward direction is allowed, then the corresponding backward time attributes are set to a very large value (this action is equivalent to setting a restriction attribute). Note that get-on and get-off time ($t_2$ and $t_4$) are modeled as time cost attributes of lines interconnecting bus stops and virtual stops: get-on is forward and get-off is backward time.

Table 2. Cost attributes of the bus network

<table>
<thead>
<tr>
<th>Name</th>
<th>Unit</th>
<th>Data Format</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forward_Time_NonPeak</td>
<td>minute</td>
<td>Float</td>
</tr>
<tr>
<td>Backward_Time_NonPeak</td>
<td>minute</td>
<td>Float</td>
</tr>
<tr>
<td>Forward_Time_Peak</td>
<td>minute</td>
<td>Float</td>
</tr>
<tr>
<td>Backward_Time_Peak</td>
<td>minute</td>
<td>Float</td>
</tr>
<tr>
<td>Street_Length</td>
<td>meter</td>
<td>Float</td>
</tr>
</tbody>
</table>
The last cost attribute in Table 2 - Street_Length - is used for calculating walking times $t_1$ and $t_5$ between the get-on/get-off bus stops and the start/destination places.

5. Data acquisition

The base map used in this work is a tourist map of Hanoi City published in 2004. Since this map is in analogue form, it was scanned at 200dpi resolution and georeferenced by coordinates of the map grids. Based on the georeferenced map, the features described in Table 1 are digitized.

Attribute data and photos are collected in the field. The travel time attributes are measured manually at appropriate time (peak and non-peak hours). The time intervals between 2 consecutive buses for calculating $t_2$ are taken from data of Hanoi Transportation Corporation (Transerco).

6. Software development and system deployment

HBIS can be deployed as an application installed on personal computers or as an internet service (users will access the system via web browsers). The first solution can be implemented as a standalone application (required ArcGIS Engine) or as an extension of ArcGIS Desktop software. The second, internet solution, required ArcGIS Server with Network Analyst extension. Whatever solution is chosen, there is a need for additional tool programming because standard ArcGIS functionality does not meet all requirements of the system.

Thus, standard ArcGIS’s Identify tool has limited capability in displaying images and photos associated with the map features. For displaying photos of bus stops and surrounding specific objects, the authors have developed a new identify tool called BIdentify by using Borland Delphi 6.0 software. This tool was developed as a COM (Component Object Model) server implementing 2 interfaces ICommand and ITool for connecting to the main application (Fig. 2).

![Figure 2. BIdentify tool is developed as a COM server](image)

When BIdentify is activated and the user clicks on the desired map feature, the tool connects to an external database, if any, to query attribute data and displays it on
the screen. If some fields contain paths to image files in database then BIdentify will open them and display images instead of textual data.

For user’s convenience, HBIS has ability to search for streets, bus lines, bus stops and specific objects by their name (or number). This is actually the Search By Attribute tool of ArcGIS, but its use is not easy for non-experienced user. Because of that, the authors have developed another tool called StSearch, which implements the following simple query:

\[
\text{SELECT *}
\from \text{LayerName}
\where \text{[Name]} = "\text{FeatName}"
\]

where LayerName is the name of layer containing searched features, FeatName is the name of these features. If the features are found, StSearch will display them on the screen at desired scale. For communication with ArcGIS, StSearch is implemented as a COM server in the same manner as BIdentify. Note that all of the software tools use Unicode character set and thus the system can manage and display data in virtually any language.

7. Test and discussion

For testing purpose, the system is deployed as an extension to ArcGIS desktop. The users interact with the system via HBIS Toolbar with 6 buttons as shown in Fig. 3.

![Figure 3. The HBIS toolbar](image)

The buttons of HBIS toolbar have the following functions:

- **1. StSearch**: searches for streets, bus lines, bus stops and specific objects by their name;
- **2. BIdentify**: shows information about features including their photos;
- **3. New Route**: creates new route in order to perform fastest path analysis;
- **4. Network Location**: defines start, destination and intermediate locations on the map for preparing the fastest path analysis;
- **5. Solve**: performs the fastest path analysis;
- **6. Direction**: shows information about the fastest travel route.
For searching features by their name, the user clicks the StSearch button on HBIS toolbar, in the displayed dialog box defines search mode (for streets, bus lines,...) and choose the name of searched feature. If the feature is found, the system zooms on it at the maximum scale defined by the user. Figure 4 is an example of searching Dich Vong Street.

![Figure 4. Search for Dich Vong Street](image)

When the object is found on the map, the user can display its attributes and photos by choosing BIdentify tool and click on it. The system will display a dialog box containing all information about object including its photos (Fig. 5).

![Figure 5. Displaying information about Bach Mai Hospital bus stop](image)

For searching the fastest path between places in the city, the user must create a new route (button 3 on HBIS toolbar), choose time of traveling (peak or non-peak...
hours) in Route Properties dialog box, and then define traveling places on the map by using Network Location tool (button 4 on HBIS toolbar). After clicking Solve button , the fastest path will be shown on the map as well as the travel directions window.

Figure 6 is an example of finding the fastest path from 29 Dich Vong St. to Hanoi University of Science at 334 Nguyen Trai Rd. at non-peak time (the first two time values and the last one in the Directions window are walking time). Note that there are numerous paths to travel by bus between these places (see Table 3), but the path displayed on the map is the fastest one.

Figure 6. Finding the fastest path from 29 Dich Vong to HUS at 334 Nguyen Trai
Table 3. Some possible paths for traveling from 29 Dich Vong to 334 Nguyen Trai

<table>
<thead>
<tr>
<th>Path name</th>
<th>By bus lines</th>
<th>Along streets</th>
<th>Travel time (min)</th>
<th>Path length (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>B34/44</td>
<td>34, 44</td>
<td>Cau Giay, Pham Hung,..., Nguyen Trai</td>
<td>55</td>
<td>9875</td>
</tr>
<tr>
<td>B35/21</td>
<td>35, 21</td>
<td>Cau Giay,..., Thai Ha, Tay Son,..., Nguyen Trai</td>
<td>51</td>
<td>8702</td>
</tr>
<tr>
<td>B16/27</td>
<td>16, 27</td>
<td>Cau Giay, Lang, Nguyen Trai</td>
<td>47</td>
<td>7491</td>
</tr>
<tr>
<td>B32/27</td>
<td>32, 27</td>
<td>Cau Giay, Kim Ma,...,Lang, Nguyen Trai</td>
<td>45</td>
<td>8376</td>
</tr>
</tbody>
</table>

The results in Table 3 show that the shortest path is B16/27, but the fastest one is B32/27. At first look it seems inconsistent, but detailed analysis shows that the time $t_2$ for waiting bus No 16 is much longer than that for bus No 32 (10 minutes against 5 minutes). Thus, path B32/27 is actually the fastest one.

For time accuracy assessment, the authors have made control travels along 2 tested routes and computed root mean square errors (RMSE). The results are shown in Table 4. It can be seen that the average error of traveling time is about 3 minutes, what is acceptable for most bus passengers.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Route 29 Dich Vong - 334 Nguyen Trai</th>
<th>Route Bao Son Hotel - Thu Le Zoo - Ho Tay Water Park</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fastest path</td>
<td>Bus 32 → 27</td>
<td>Bus 26 → 32 → 55</td>
</tr>
<tr>
<td>Time given by HBIS</td>
<td>45 min</td>
<td>58 min</td>
</tr>
<tr>
<td>Control travel No1</td>
<td>42 min</td>
<td>61 min</td>
</tr>
<tr>
<td>Control travel No2</td>
<td>47 min</td>
<td>56 min</td>
</tr>
<tr>
<td>Control travel No3</td>
<td>41 min</td>
<td>-</td>
</tr>
<tr>
<td>RMSE</td>
<td>3.1 min</td>
<td>2.6 min</td>
</tr>
</tbody>
</table>

8. Conclusion

Public transport always is a difficult problem of big cities in Vietnam, especially under pressure of the current intensive socio-economic development. There are existed many solutions for this problem, among those the solution of using information technology to gain the capability of current public transport system is a very effective one.

In this work, the authors have applied GIS technology to develop a bus information system for helping passengers to use the complicated bus network of Hanoi City. By using the system, it is possible to obtain information about bus lines, bus
stops, search for streets or specific objects by their names, and find the fastest path between 2 or more places inside the city with an error of about 3 minutes. For implementing these functionalities, the paper has developed a logical model of a bus network consisting of 2 groups and 5 travel time parameters, and a bus geodatabase with 5 feature classes. The data management tool is designed as COM servers to extend standard functionality of ArcGIS software.

The future research will be focused on extending the system for other kinds of urban transport (bicycle, motorcycle,...) and deploying on the internet for wider and easier access.

REFERENCES
