AN ALGORITHM TO DETERMINE OPTIMAL PATH FOR GIS BASED ROAD NETWORK

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ABSTRACT

Traffic congestion is becoming a serious problem in modern cities across the globe. With the complex network of a modern city, finding optimal path for road user is a challenging task. Network analysis in Geographic Information Systems (GIS) provides strong decision support for users in searching shortest route, which considers only a single network weight. Unlike other shortest path algorithm, the author developed an algorithm which could be extensively used for GIS based global position of transport network to determine optimal path. A network matrix were generated using adjacent nodes (vertices) and travel cost (travel time). Another turn matrix was generated using adjacent nodes of intersection to estimate intersection delay and turn control. The algorithm was implemented in C++ environment.

Key words: *Algorithm, Congestion, GIS, Optimal, Matrix.*

1.0 INTRODUCTION

A broad range of diverse technologies, known as Intelligent Transport Systems (ITS), holds the answer to many of these transport problems (Kumar et al., 2003, Rao et al., 2003;ESRI, 2004). A route planner to provide advance traveler information, in this regard, is considered to help a traveler to make the desired trip effectively and efficiently. The present study thus intends to develop a methodology/technique to determine optimal route based on shortest travel time / lowest impedance between a selected pair of origin and destination for GIS based road network (road network of Dhaka City would be used as a case study). Relevant key issues are mentioned in the following paragraphs.

For a given origin and destination, one is always tempted to use the shortest distance route (Kumar et al., 2003; Wu et al, 2005; Inro Consultants Inc., 2003). But this need not always is the best (optimal) route, especially in emergency situations, wherein shortest travel time is to be preferred over shortest distance. A shorter route does not always translate to shorter travel time, because it may be narrow in width or it may have higher volume of traffic, or more numbers of signals and turns and so on (Thirumalaivasan,Guruswamy,2006). Weighted graphs (Cormen et al., 2002; CDA International Ltd.,2006), which are a pervasive data structure in computer science and algorithms (Shekhar and Fetterer,1996) for working with them are fundamental for the problems of computing optimal routes between nodes when each edge has an associated length or “weight” to represent the road and traffic condition.

An optimal path/route algorithm can be describe as a (directed) graph G= (N,E,C) consists of a node set N, a cost set C, and an edge set E (Shekhar and Fetterer,1996). The edge is a subset of the cross product N*N. Each element (u,v) in E is an edge that joins node u to node v. Each edge (u, v) is associated with a cost C (u, v). Cost C (u,v) takes values from the set of real numbers. A node v is a neighbor of node u if edge (u,v) is in E. An optimal path from node u to node v is the path with the smallest cost.

However, optimal path algorithms are very rarely available in literature, which explains only the conceptual framework (Zografos and Androutsopoulos, 2006; Liao,2004). Furthermore, literature reveals that most route selection techniques are based on shortest path on the basis of distance or travel time not considering road type, road geometry, land use, intersection queue length, signal timing, flow restriction, etc. Also most of them need to install specific GIS software in the computer for their visual display.

To implement the algorithm some database regarding traversing nodes and travel cost is essential. Sections 2 through 4 briefly discussed the basic database acquisition procedure in brief.

Travel cost (travel time) data was calculated using the Equation 1.1.

Travel time is the sum of the mid –block travel time and intersection travel time, and can be formulated as :

$$T = \sum_{i=0}^{n} (T_m + T_d) \ldots\ldots\ldots\ldots\ldots\ldots (1.1)$$

Where,

T = total travel time, sec

i = total number of segment (s) to be traversed between O-D pairs

Tm = time required to traverse mid-block segment (s), sec

Td = intersection delay adjacent to mid-block segment, sec

2.0 SPATIAL NETWORK

There are 6608 arcs those represents road network of the study area. The study network was the selected road Network of Dhaka City Corporation (DCC, 2003) as shown in Figure 2.1. The spatial network is composed of Primary road and secondary road only. Other types of road network and railway were excluded in the study.

Figure 2.1: Spatial Network of the Study

3.0 METHODOLOGY

The methodology is presented in the flow chart as shown Figure 3.1 below.

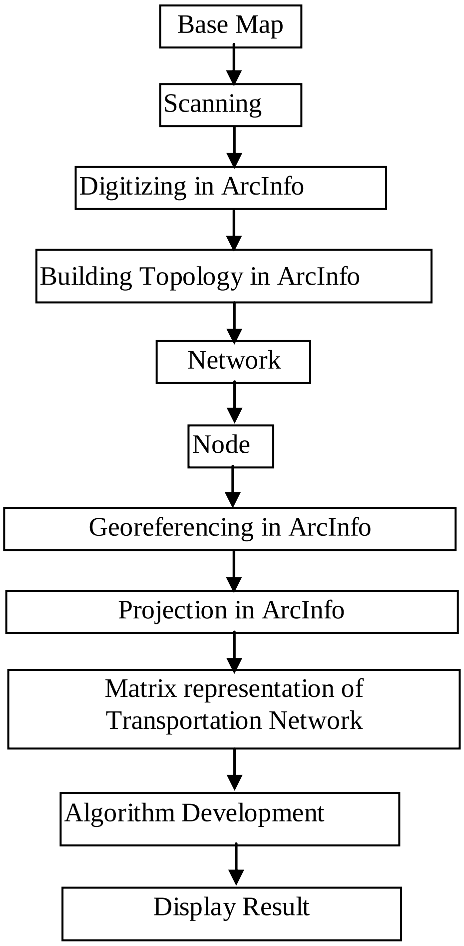

Figure 3.1: Framework of the Methodology

3.1 Spatial (GIS) Database Development

DCC base map of scale 1:30000 (DCC, 2005) would be the main source of the spatial data. Basic steps for acquisition of spatial database development are base map collection, scanning, digitization, building topology, missing data collection, georeferencing and projection.

3.2 Non-spatial Database Development

Travel regarding free flow speed, intersection delay, signal cycle time, signal green time, restriction on vehicle movements, restriction on u-turns, stops, barriers, etc., would be considered as non-spatial data and stored in predefined dBASE tables in MS Access format. Some of the data have been collected from STP (The Louis Berger Group, Inc. and Bangladesh Consultants Ltd ,2005) and (DUTP, 1998). Appropriate delay function have been developed in this regard (TRB,1985 and Chung and Akcelik,1992). Moreover, further traffic and road network data have been collected from relevant institutions (BRTA, RHD, etc.) and through small scale physical survey.

4. REPRESENTATION OF TRANSPORT NETWORK

The transport network is composed of adjacent vertices. The GIS based transport network is showed in Figure 2.1. Each individual road segment is consists of adjacent vertices.

4.1 Vertices of the network

There are 4458 nodes (vertices) available in the study area network. The vertices have been generated from the transportation network as shown in Figure 2.1 using ArcInfo GIS and showed in Figure 4.1 as below (ArcInfo, 2008).

Figure 4.1: Adjacent Nodes of the Study Network

4.2 Tabular format of vertices

Ultimately the vertices need to convert into tabular format, the table of vertices has been generated in ArcInfo. Travel cost (network weight) has been obtain from different analytical result (HCM, 2000). The prototype of the attribute table is showed in Table 4.1 below. The whole Table is available in the database.

Table 4.1: Node Attribute Table

FNode	TNode	Duration		Travel Cost (Time,sec)
		From	To	
1886	1836	6:00	7:00	73.38
1886	1836	7:00	8:00	73.38
1886	1836	8:00	9:00	73.38
1886	1836	9:00	10:00	73.38
1886	1836	10:00	11:00	73.38
1886	1836	11:00	12:00	73.38
1886	1836	12:00	13:00	73.38
1886	1836	13:00	14:00	73.38
1886	1836	14:00	15:00	73.38
1886	1836	15:00	16:00	73.38
1886	1836	16:00	17:00	73.38
1886	1836	17:00	18:00	73.38
1886	1836	18:00	19:00	73.38
1886	1836	19:00	20:00	73.38
1886	1836	20:00	21:00	73.38
1886	1836	21:00	22:00	73.38
1886	1836	22:00	23:00	73.38
1886	1836	23:00	0:00	73.38
1886	1836	0:00	1:00	47.70

Source: Node Coveage

To determine optimal path that network was converted in matrix format. The prototype of matrix is showed in Figure 4.2. Similarly, individual turn matrix was generated as shown in Figure 4.3.

$$\begin{vmatrix} v_1 & v_2 & c_1 \\ . & . & . \\ . & . & . \\ v_{n-1} & v_n & c_n \end{vmatrix}$$

Figure 4.2: Network Matrix

$$\begin{vmatrix} v1 & v2 & v3 & c1 \\ . & . & . & . \\ . & . & . & . \\ vn-2 & vn-1 & vn & cn \end{vmatrix}$$

Figure 4.3: Turn Matrix

Where
v_1, v_2, v_3, ... v_n, represents nodes of network
c_1, c_2, c_3, ... c_n, represents network cost (weight)

5.0 ALGORITHM

An algorithm is a finite set of instructions that, if followed, accomplishes a particular task. In addition, all algorithms must satisfy the criterias: Input, Output, Definiteness, Finiteness, Effectiveness.

5.1 Notations

Notations used in the algorithm are mentioned below:

∈	Belongs to
←	Assignment
==	Equal
+	Addition

5.2 Elements

The proposed algorithm composed of set of vertices (V) and edges (E). Another element is the network cost, which is the time require to traverse between vertices.

5.3 Proposed Algorithm

The proposed algorithm is based on the back tracking, because of ranked paths are to be calculated. The proposed algorithm is also involved with integration of network impedances, landuse, etc., so that optimal path can be achieved. The algorithm notations, it's elements have mentioned in sections 5.1 and 5.2.

Algorithm Ranked Optimal Path (Input: edge list E, vertex list V, source)

1. For every vertex v ∈ V
2. Color [v] ← white
3. Parent [v] ← -1
4. Cost [v]] ← 0
5. Call Backtrack (source)
6. End

Algorithm backtrack (input: source vertex v)

5. Color [v] ← gray
6. While there is any vertex u adjacent to v
7. Begin
8. if (color [u]==white)
9. Begin
10. Parent [u] ← v
11. Cost [u] ← Cost[v] + Cost (v,u)
12. Backtrack(u)
13. Color [u] ← White
14. END
15. END
16. END
1. if v is destination node
2. begin
3. save path from source to v
4. END

5.3.1 Execution procedure of the proposed algorithm

A step-by-step procedure to execute the algorithm describes below. At each step of the algorithm, the contents of the reached table and the scanned table will be shown along with a map showing the progress of the algorithm.

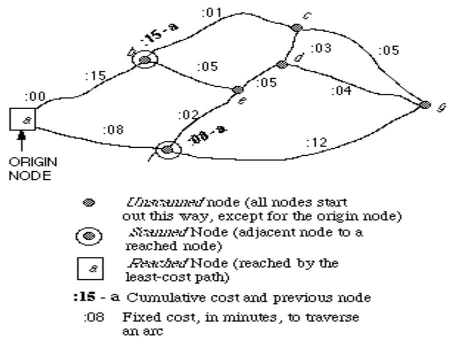

Figure 5.1: Spatial Network and O-D Node Used for Executing Algorithm

Step1 :Set the origin node as reached. Scan the adjacent nodes (nodes b and f)
Step 2:Pick the scanned node with the lowest cumulative cost
Step 3: Scan all the nodes adjacent to the node just reached
Step 4: Pick the scanned node with the lowest cumulative cost
Step 5: Scan all the nodes adjacent to the node just reached
Step 6:Repeat steps 3 and 4 until reaches in the destination node

The only entries left on the scanned table are for node g. There are no nodes adjacent to node g that has not been reached. That is, there is nothing left to scan, and this phase of the path finding algorithm is complete. The scanned table can be thrown away at this point. The algorithm has now determined the least-cost path from all nodes to the origin node.

To trace the least-cost path from a to g, it is necessary to follow the previous node. Starting at node g (Step [1]), go to node d (Step [2]), to node e (Step [3]), to node f (Step [4]), to node a (Step [5]).

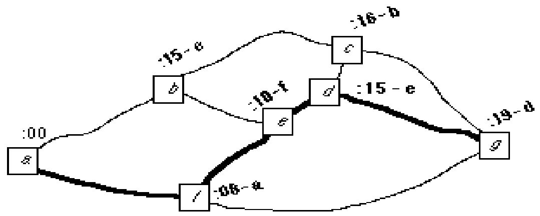

Figure 5.2: The Least-cost Route (optimal route) from a to g.

6.0 EXPERIMENTAL RESULTS

A GIS road network for Dhaka city is contain 4458 nodes and 6230 arcs as shown in Figure 2,1 and 4.1 respectively. When implemented the algorithm in C++ environment ranked optimal path were found as in Figure 6.1 below. A prototype of the ranked path between origin node to destination node were found as shown in Figure 6.1 below.

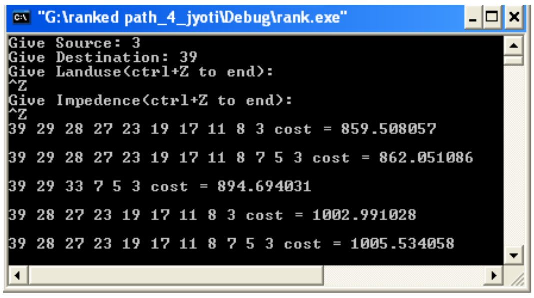

Figure 6.1: Optimal Path Between Given Origin and Destination

6.0 CONCLUSIONS

The main objective of the paper was to discuss the feasibility of the algorithm. Due to test of experimental results spatial and non-spatial data acquisition procedures were also discussed in brief. The developed algorithm is ideally expected to find a set of ranked optimal paths. When works with huge vertices it is essentially be used higher configured processor and RAM to obtain result quickly. Back tracking is an important criteria to determine ranked optimal path using the algorithm.

REFERENCES

ArcInfo 7.2.1 (2008). “Arc-Node Topology”. On-line help of ArcInfo 7.2.1, Environmental System Research Institute, 380 New York Street, Redlands, California, USA

CDA International Ltd. (2006). “ Manifold® System Release 7.x”. http://exchange.manifold.net/manifold/manuals/manifold/manifold.htm#networks/graph_theory/graph_theory_glossary.htm

Chung, E., Young, W., and Akcelik, R. (1992)."Comparisonof Roundabout Capacity and Delay Estimates From Analytical and Simulation Models". 16th conference Proceedings -Part5, Australian Road Research Board (ARRB) Limited

Cormen, T.H., Leiserson, C.E, Rivest, R.L, and Stein, C. (2002). “Introduction to Algorithms”. The MITPress,Cambridge, Massachusetts, London, England

DCC (2003). “Road maintenance plan of DCC road network for 2002-2003”. Dhaka City Corporation, Dhaka

DCC (2005). “Base Map of Dhaka City Corporation”.DhakaCity Corporation, Dhaka

DUTP (1998). “Dhaka Urban Transport Project, Phase II(1998), Draft Final Report”. PPK, Mot DocDonald andDevelopmentDesign Consultant (DCC), Dhaka

ESRI (2004). "ESRI GIS Partner Solutions and Services for the Transport Industry". www.esri.com/Transportation/ library/brochure/pdfs/ transportation_bps.pdf

HCM (2000). “Highway Capacity Manual”. Transportation Research Board, National Research Council, Washington, DC, USA

Inro Consultants Inc. (2003). "EMME/2 User's Manual Software Release 9". Inro Consultants Inc., Montreal (Quebec), Canada.

Kumar, P., Reddy, D., Singh, B. (2003). "IntelligentTransport System Using GIS".Map India Conference 2003, © GIS Development.net

Liao,T. (2004). "Tabu Search Algorithm for Dynamic Vehicle Routing ProblemsUnderReal-Time Information".Transportation Research Record: Journal of the TransportationResearch Board, No. 1882, Washington, D.C., pp. 140-149.

Rao, V., Trinadha, Bhardwaj, Alok, and R,Ch.V.S.(2003).“Intelligent Transport Systems (ITS): A Technology Solution For 21st Century Public Transport System Management”. www.tcs/0_practices/transportation/download/intelligenttransportation_system.pdf

Shekhar, S. Fetterer, A. (1996). “Path Computation in Advanced Traveler Information Systems”. Computer Science Department, EE/CS 4-92 UniversityofMinnesota, Minneapolis, MN, 55455 www.cs.umn.edu/research/shashi- group

The Louis Berger Group, Inc. and Bangladesh Consultants Ltd (2005). "Strategic Transport Plan (revised final draft)". Ministry of Communications, Government of the People's Republic of Bangladesh.

Thirumalaivasan, D., and Guruswamy,V. (2006). "Optimal Route Analysis Using GIS". AnnaUniversity, India www.gisdevelopment.net/application/utility/transport/index.htm

TRB (1985).“HighwayCapacity Manual. Spacial Report 209". Transportation Research Board, National Research Council, Washington, D.C

Wu, Yi-Hwa, Miller, H.J., and Hung, M.C. (2005). “ A GIS-based Decision System For Analysis of Route Choice in Congested Urban Road Networks”. Digitally Integrated Information Laboratory & Department of Geography, University of Utah, 260 S. Central Campus Dr. Room 270, Salt Lake City, UT 84112-9155. E-mail:{wu.yi-hwa, Harvey.miller, mhung}@geog.utah.edu

Zografos, K.G and Androutsopoulos, K. N.(2006)."Algorithmsfor Determining Optimum Itineraries inaMultimodalUrban Transportation Network". TRB 2006 Annual Meeting CD-ROM, USA.