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Dijkstra algorithm interactive training software development for network analysis applications in GIS

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Abstract

Process of route optimization is one of the basic applications of Network Analyses in Geographic Information Systems. In mathematical background of network analysis applications are graph theory and graph algorithms. Primary graph algorithm employed in process of route optimization is Dijkstra's Algorithm. Dijkstra's Algorithm is placed on the top of linear methods which yield exact solutions. Geographic Information Systems analyses such as the shortest route, the shortest duration and route with the least traffic are solved through Dijkstra's Algorithm. In this study, an interactive training software program, developed for educational use in Geographic Information Systems and Graph Theory classes at postgraduate degree, is introduced. This software provides students with the opportunity to use Dijkstra's Algorithm on graphs which they have designed by themselves and teaches details of algorithm, its working principles and structure of data to them, step by step, through interactive messages and graphics.

Keywords: Geographic information systems; Graph theory; Interactive learning; Network analysis, Route optimization; Dijkstra Algorithm

1. Introduction

Systems or structures such as highways, railways, rivers, pipelines, telephone and electricity lines which are related to each other with linear features are called network. It is possible to get from one point to another on network structures [1]. Activities such as transportation of humans, transportation and delivery of services and goods, delivery of sources and energy, and data communication take place in definable network structures [2].

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1. 1. Network analysis applications in geographic information systems

Transportation or journeys from one location to another make up the subject matter of network analyses [3]. Network analyses are locational analyses that help to yield results in order to make decisions through connection types of geographical features which connect with each other and have network structure (Fig. 1).

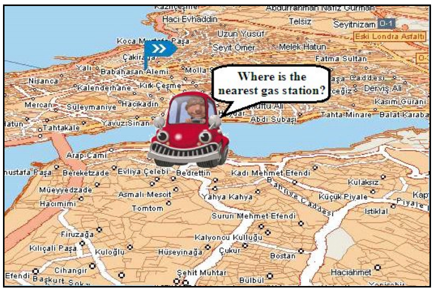

Fig. 1. Deciding depending on the shortest distance.

First examples of such networks that come to mind are streets of a town, energy distribution lines, service network of an airport or structure of water disposal lines. Investigations and analyses to make optimal decisions on these systems are called Geographic Information Systems (GIS) Network Analyses. Applications such as arrival of ambulances, fire engine and police cars at required places in the shortest time possible, where fire stations should be located or which buildings' power can be controlled in case of a disorder are also included in network analyses [4]. Problems of a wide range, from distribution route modeling to post earthquake planning, from electricity lines disorder to addressing, from investment analyses to security applications are solved through network analyses [5].

Locational objects used for network analyses must be joined in a vectorial structure, as connected to each other with proper lines in network structure. However, data, the arc-node topology of which is formed, enable network analyses to be done [6]. Arc-node structure is a topological structure and is based on graph theory. And primary analysis type in network analyses is the process of Route Optimization between two points.

1. 2. Route optimization between two points

Processes of deciding which connection is the most appropriate solution when there is more than one connection between two points are known as route optimization in Geographic Information Systems [4]. The most appropriate solution may mean the shortest path between two points (Fig. 2) or some other criteria which provide certain features can effect route optimization. For instance, for an ambulance, a path with the least traffic between the point where it has picked the patient and hospital, relatively longer, yet through which the ambulance can get to its destination in the shortest time can be the best solution. Similarly, of two paths between two cities, the one with better topography and ground structure is preferable even if it is longer.

Find Closest Facility can be mentioned as a more comprehensive route optimization analysis. Find Closest Facility is the process of detecting several points around a certain point and paths between them, and choosing the shortest one. For instance, Find Closest Facility is employed to determine which one of ambulances that will set out from neighboring hospitals will get to scene the soonest (Fig. 3). For this reason, first of all, shortest paths between all hospitals and scene are determined and then the shortest one of these paths is introduced to user.

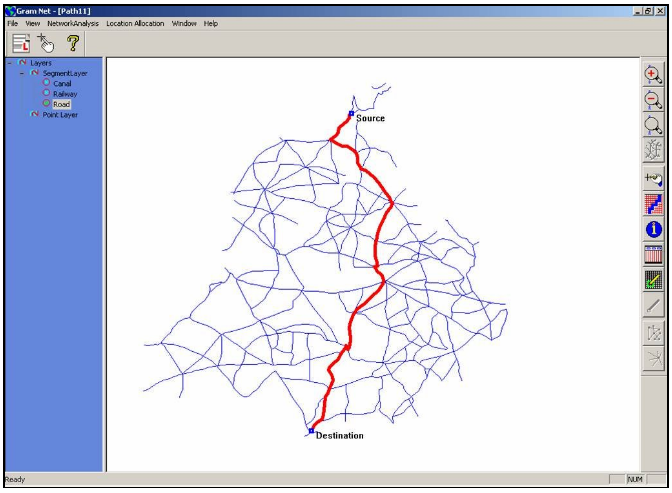

Fig. 2. The shortest path between source and destination [7].

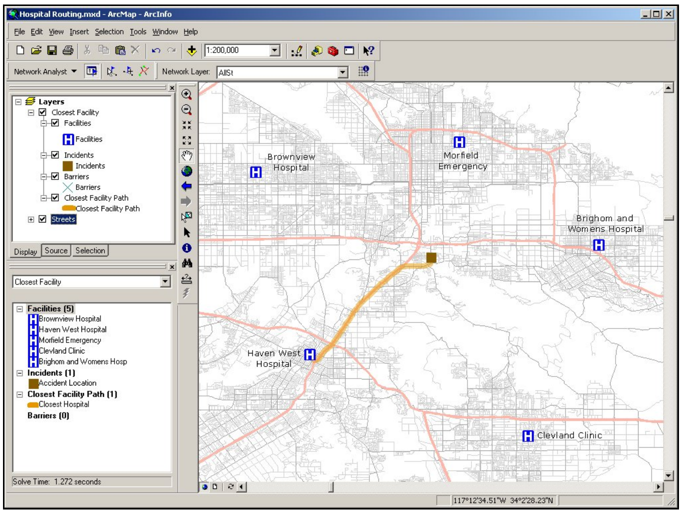

Fig. 3. Determining the closest hospitals to scene through Find Closest Facilty [8].

Mathematical background of route optimization in GIS software is based on the method developed by Dijkstra. Dijkstra's Algorithm is the most widespread method used to calculate routes with minimum cost (shortest route, time, etc.).

1. 3. Dijkstra's algorithm

Determining the optimal route between two nodes of a graph is actually the process of determining the route with the least cost between these two nodes. As stated above, the notion of cost may not always mean length. If costing has been made based on time (factors such as rough surfaces and traffic density may require considering time instead of length), the shortest path found will be denominated in terms of time. It should be remembered that what is meant by the shortest path is the path with the least cost.

Path solution with the least cost developed by Edsger W. Dijkstra in the year of 1959 and which can also be applied on directed graphs is known as Dijkstra'a Algorithm [9].

Algorithm works on graphs the cost of lines of which is numbered zero or greater than zero. According to this algorithm, in order to find shortest paths (with least cost) leading from any point of the graph to all other points, it is necessary to do iteration as equal to one less than the number of total nodes starting from that point. During this process, distance of each node to the starting node (root node) is calculated and recorded. Then, the smallest one of these nodes, the distances of which have been calculated, is marked. In the next stage, the same process is done for all nodes starting from the marked one and is continued until all other nodes are reached. By forming this tree that covers all nodes, the cost of transportation between the root node and all other nodes is enabled to be the smallest.

To detail the subject using an example, let us consider that the graph in Fig. 4 is a path tree consisting of six cities and distances between each are stated. When A is chosen as the root node, the process to find optimal routes to other nodes is, step by step, as follows:

1. There are two alternates when started from A node; K and B nodes. Distances between these and A are calculated and these values are written in them. Then, the one with smaller value, that is B node, is selected and marked with arrow (Fig. 5).

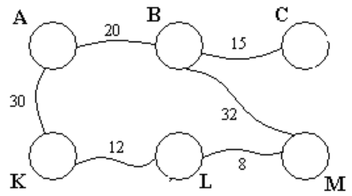

Fig. 4. A six-node weighted graph.

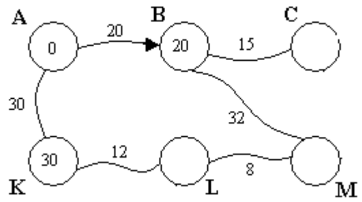

Fig. 5. **T**he smallest value belongs to B.

2. Nodes starting from B, the node which was marked in the previous stage, are checked and their distances are written inside them. According to this, C=35 and M=52. Then, all nodes in which the distance information has been written, except for root node (A) and marked nodes (B), are checked and the smallest one is marked. Therefore, as C=35, M=52 and K=30, K is selected and marked with arrow, based on the route which has got the value written in it (Fig. 6).

3. As the last marked node is K, following nodes are checked and their distances are written. In this sense, L, which is the node following K, is valued 42. After that, when non-marked nodes the distances of which have been written inside them are checked, it is seen that C is 35, M is 52 and L is 42. As C=35 is the smallest and it has gotten this value from B, it is added to BC line with arrow (Fig. 7).

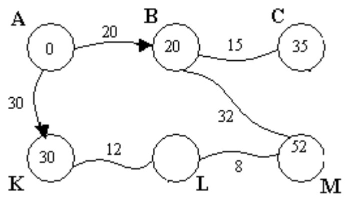

Fig. 6. Node with the smallest value is K.

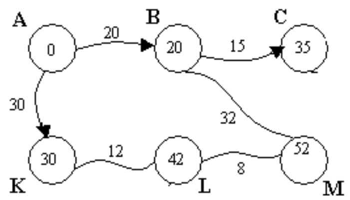

Fig. 7. The smallest value belongs to C node.

4. Later, the smaller one of the last two nodes is selected (L) and marked (Fig. 8).

5. Nodes following the last marked node (L) are checked and valued. According to this, we get M 42+8=50. As this value is smaller than 52 which was based on B, 52 is crossed out and replaced by 50 and line coming from L is marked (Fig. 9).

After all these processes, the shortest paths leading to all other nodes for the graph above in which A node was chosen the root node are determined as in Fig. 10.

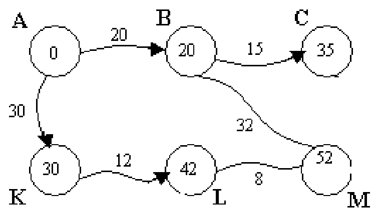

Fig. 8. L, smaller one of the last two nodes.

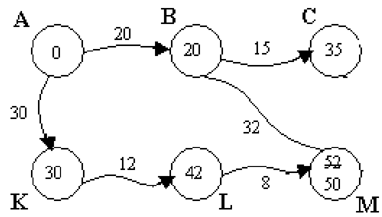

Fig. 9. Minimal value of M node.

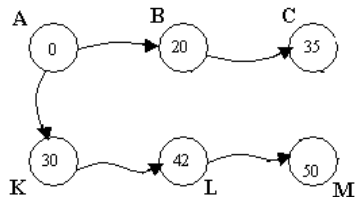

Fig.10. Shortest paths to other nodes from A node.

2. Dijkstra's algorithm interactive training software

In this study, an interactive training software program has been developed for educational use in GIS and Graph Theory classes. This software provides students with the opportunity to use Dijkstra'a Algorithm on graphs which they have designed by themselves and teaches details of algorithm, its working principles and structure of data to them, step by step, through interactive messages and graphics (Fig. 11).

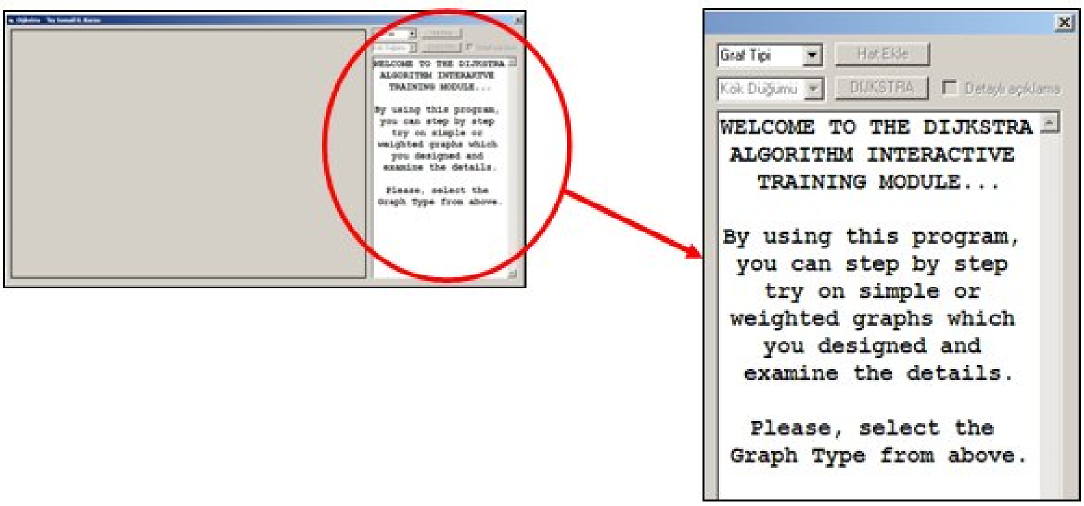

Fig. 11. Users can work the Interactive Training Software on graphs designed by them.

Then, Dijktra's Algorithm works on this graph, based on selected root node and users are directed in a similar way to the example explained in Section 1. 2. All stages of the algorithm are simulated visually, clearly and in detail in graphical interface. Also, written messages pop up on user's screen in every stage, explaining current processes in detail (Fig. 12).

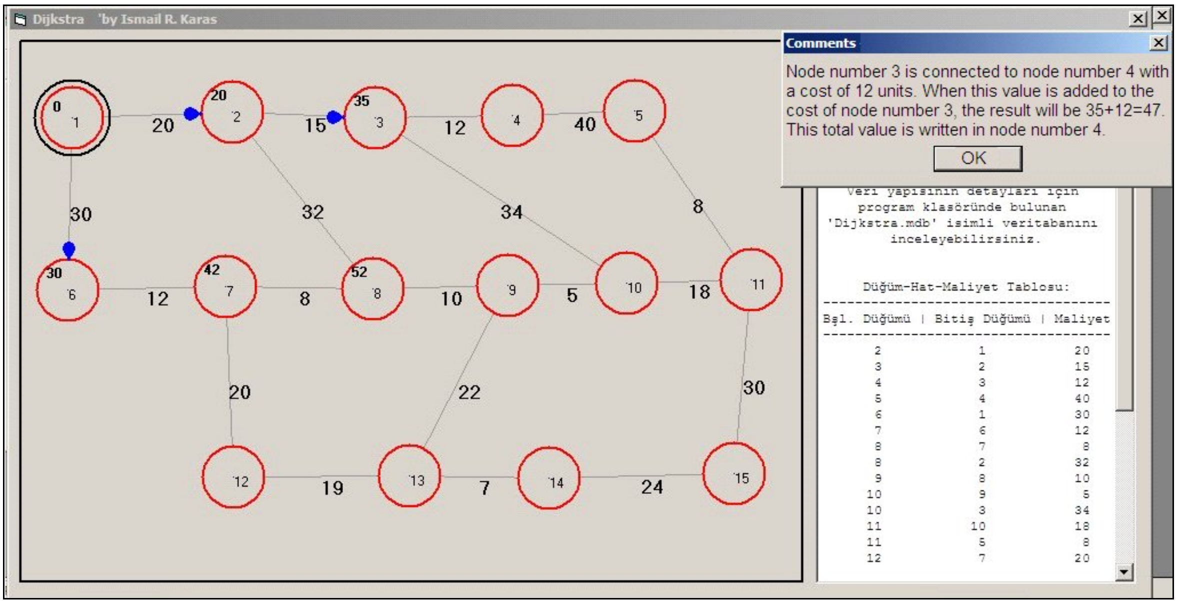

Fig. 12. Interactive Training Software enables users to learn visually, step by step, through interactive messages and graphics.

After all stages are completed, the Shortest Path Tree is introduced to user visually (Fig. 13). “Arc-Node-Cost Table” and “Shortest Paths Table” of the tree in question are reported in detail (Figs. 14 and 15).

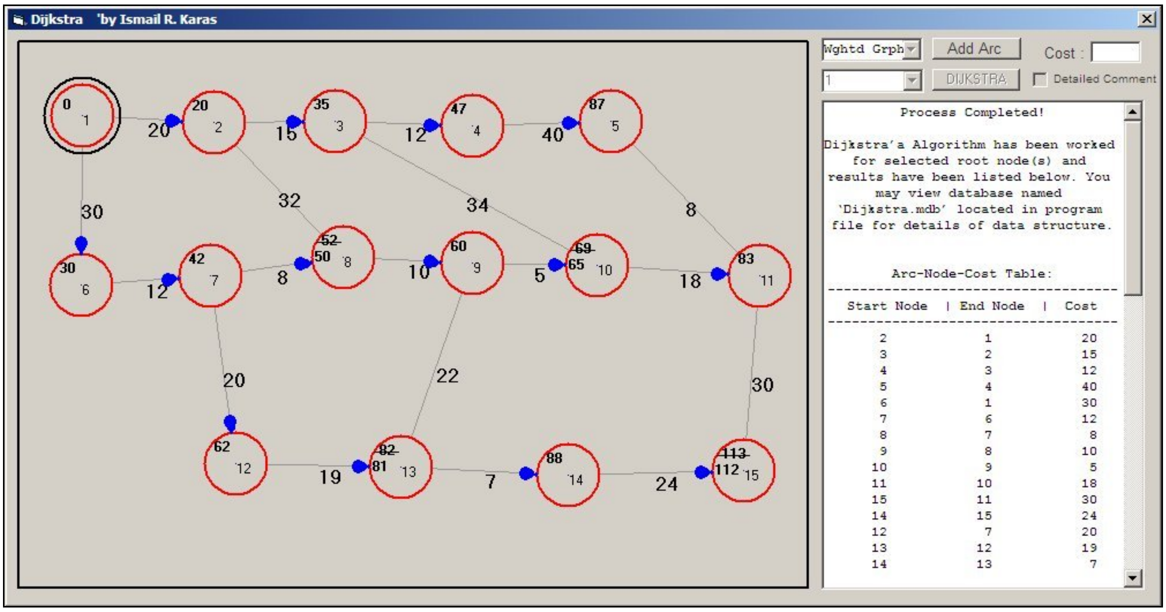

Fig. 13. Introducing the shortest path tree as graphic and tabular after completing algorithm.

3. Conclusions

Visual learning by making and using simulations and models can enable and enhance learning [10]. It is a proven method resulting in an easier and more effective method of transmitting skills. Students can understand theoretical concepts much easier if they can see,

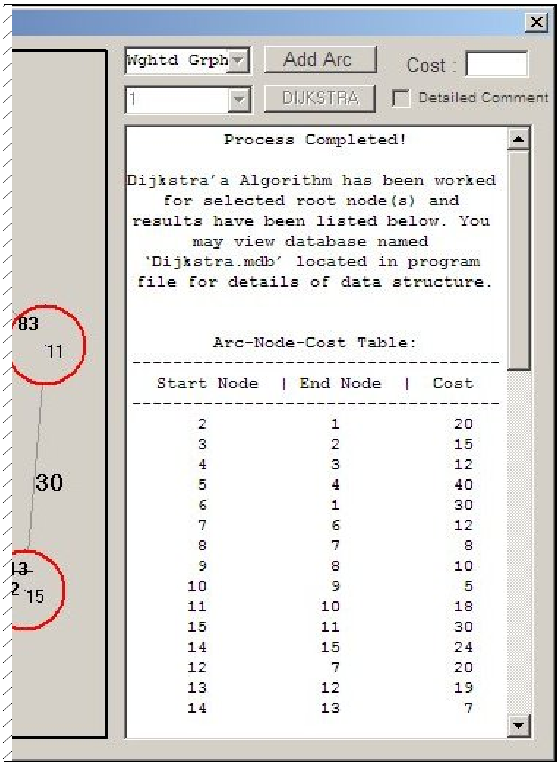

Fig. 14. Arc-node-cost table.

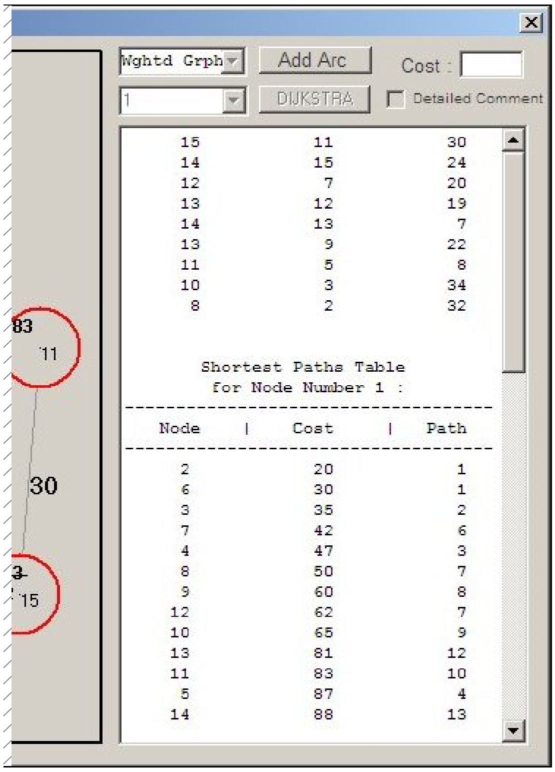

Fig. 15. Shortest paths table.

use them, or interact with. Learning by doing uses methods that help students to open their mind [11].

In this study, an interactive training software program for educational use in Geographic Information Systems and Graph Theory classes at postgraduate degree has been developed. This software provides students with the opportunity to use Dijkstra'a Algorithm on graphs which they have designed by themselves and teaches details of algorithm, its working principles and structure of data to them, step by step, through interactive messages and graphics.

This study has shown that such interactive and visual training sets contribute to theoretical training to a great extent and thus students can have the opportunity to learn subjects tangibly and clearly.

In addition, it was observed that the brain-based learning environment did not create any difference in students' attitudes towards the course [12-17]. Moreover in future studies students' attitudes to the physical education course will be observed in brain based multicultural environments [18-30].

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