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Shortest Path Analysis Based on Dijkstra's Algorithm in Emergency Response System

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Abstract

In emergency situations, finding suitable routes to reach destination is critical issue. The shortest path problem is one of the well-known and practical problems in computer science, networking and other areas. This paper presents an overview on shortest path analysis for an effective emergency response mechanism to minimize hazardous events. Both graph theory and network analysis in GIS was discussed for the purpose of modeling and analyzing traffic networks. A transportation network can be referred to as a valued graph consisting of a set of vertices and a set of edges. In order to compute length of the shortest path from the source to each of the remaining in the graph, we illustrated Dijkstra's algorithm and its program. Based on the integration of Geographic Information System (GIS), web services and Asynchronous JavaScript and XML (Ajax) technologies, we provided a web application for finding optimal routes from locations of specialized response team stations to incidents site so as to maximize their ability to respond to hazard incidents.

Keywords: *shortest path analysis, emergency response, GIS, Dijkstra's algorithm*

1. Introduction

The emergency response system in public emergencies is the system by a series of posed action that peoples have taken after the public emergencies occurred,and the main purpose is to reduce the degree of damages induced by public emergencies,to prevent the event's derivation or further expansion [1]. All such situations might be carried out from fires, explosions,traffic accident,terrorism,and natural disasters. Universal purpose of any disaster management system is to deliver emergency services such as police, fire brigade and medical service as quickly as possible in affected [2]. During an emergency it is very essential to have accurate data and take prompt actions. An effective emergency response mechanism might be possible to minimize and control hazardous events by preparing for such events prior to such an occurrence,and by a rapid response afterwards.

In case of any incident, the emergency response officer needs a smart decision support system to reach the incident location as soon as possible [3]. There is a need for fastest possible response both in terms of dispatching the emergency services to the location of disaster as well as evacuation of the population from that location. This requires having path analysis that would enable the routing and re-routing of vehicles from the various key locations including hospitals, fire and police departments to the event scene and from the event scene to shelters, hospitals, or other locations.

Geographic Information Systems (GIS) was designed to support geographical inquiry and, ultimately, spatial decision making [4]. The value of GIS in emergency response arises directly from the benefits of integrating a technology designed to support spatial decision making into a field with a strong need to address numerous critical spatial decisions. For this reason, new applications of GIS in emergency management have flourished in recent years along with an interest in furthering this trend.

In emergency management, there are many subjects which have to cooperate during solution of crisis situation.GIS holds the capability to integrate maps with detailed database information and images, and turns ordinary maps into smart maps that respond to queries and helps in complex analysis [5]. With its ability to relate geographical and attribute data, GIS can be an effective and efficient platform for the management of information. GIS provides a means of rapid data access and query based on both geographic location and attribute data.

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Recently, much work was carried out in the application of exiting studies for emergency response systems considering shortest path analysis.Ming-Hsi Hsu, et al. [6] developed a GIS based decision support system to enhance the emergency operations during typhoon attacks in Taiwan; M.H. Xu, et al. [7] make some changes in the original Dijkstra's algorithm and obtain a new improved Dijkstra's shortest path algorithm; Oded Berman, et al. [8] presented a novel methodology to determine the optimal design of a specialized team network so as to maximize its ability to respond to such incidents in a region. Rui Chen, et al. [9] developed a set of design principles that are grounded in emergency management concepts and also in the insights from the real response managers in the Western New York area.

2. Graph Theory and Network Analysis

There are classical problems presented as graphs such as shortest path, longest path, travelling salesman problem. From the view of an emergency response system, it is an important issue to reduce the transmission time through the network by analyzing the spatial network with search procedure. Finding the shortest path from rescue sites to accident point through a road network is crucial for emergency services.In order to take prompt actions on a serious accident, it is important to construct an appropriate transportation network.

The graph theory is used intensively in operations research, discrete mathematics, combinatorial optimization and network analysis [10]. Graphs provided a powerful tool to model objects and relationships among objects. Graphs are defined by a set of vertices and a set of edges, where each edge connects two of its vertices. Graphs are further classified into directed and undirected graphs, depending on whether the edges are directed [11]. A graph structure can be extended by assigning a weight to each edge of the graph. Graphs with weights, or weighted graphs, are used to represent structures in which pairwise connections have some numerical values. For example if a graph represents a road network, the weights could represent the length of each road [12].

A network is referred to as a pure network if only its topology and connectivity are considered. If a network is characterized by its topology and flow characteristics (such as capacity constraints, path choice and link cost functions) it is referred to as a flow network. A transportation network is a flow network representing the movement of people, vehicles or goods [13]. The approach adopted almost universally is to represent a transportation network by a set of nodes and a set of links. A transportation network can be referred to as a valued graph, or alternatively a network. Directed links are referred to as arcs, while undirected links as edges. The relationship between the nodes and the arcs, referred to as the network topology, can be specified by a node-arc incidence matrix: A table of binary or ternary variables stating the presence or absence of a relationship between network elements. The node-arc incidence matrix specifies the network topology and is useful for network processing.

A graph G consists of a set V of vertices and a set E of edges such that each edge in E joins a pair of vertices in V. Graphs can be finite and infinite, when V and E are finite then G is also finite.

Graph $G = \left(V(G), E(G)\right)$ (1)

Where:

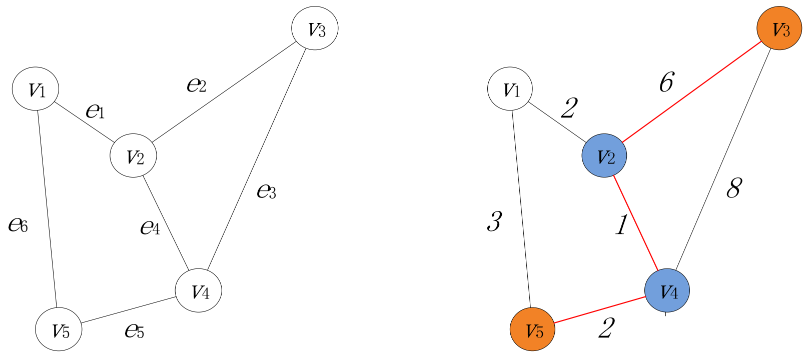
Set of vertices $V(G) = \{v_1, v_2, v_{3,} \cdots\cdots v_{\mathrm{n}}\}$ for n vertices.

Set of edges $E(G) = \{e_1, e_2, e_3, \cdots\cdots e_m\}$ for m edges with weights w such that: $W(E(G)) = \{w_1, w_2, w_3, \cdots\cdots w_n\}$, where $w \in \mathbb{R}$.

Adjacent vertices are a pair of vertices joined by a single edge and the two vertices in this case are incident to the same edge. Adjacent edges are two or more edges having a single common vertex. Figure 1(a) shows a graph G (V, E), where V(G) = {v1, v2, v3,v4, v5}, and E(G) = {e1, e2, e3, e4, e5, e6}. Order of G = |V| = 5 and Size of G = |E| = 6.

Network analysis has many practical applications, for example, to model and analyze traffic networks. A traffic network represented by a directed graph consisting of a finite set of nodes and a finite set of path which is connected to each other. Each path in the traffic network has an associated generalized cost which could be a combination of travel time, direct cost and travel distance. A path between two nodes is an alternating sequence of vertices and edges starting and ending with the vertices. The length of a path is the sum of the weights of the edges on the path.

The shortest path is a classical and main problem in network analysis and it is mandatory for GIS. It has multiple realizations and is highly dependent on the nature of transportation network and the distance between origin and destination. As mention in (1), the cost of shortest path from vertex u to vertex v is $dist(u,v)$, such that $dist(u,v) = w_{u \to v}$ is minimum. Figure 1(b) shows the shortest path for graph G as defined in (1) from vertex v3 to vertex v5 with a cost of 9.



(a) Typical graph (b) Graph of shortest path with weights

Figure 1. Typical Graph and a Graph Edges with Weights

GIS are designed to capture, analyze, represent spatial data in a way that user can easily understand. The graphs in GIS are geographically referenced, and each vertex has a well defined absolute coordinates related to earth. Network analysis problems are modeled as graph problems based on the underlying graph model of networks. Since there can be more than one path between two vertices, there is then the problem of finding a path with the minimum cost between these two specified vertices. The optimal path in traffic networks is an optimization problem that finds the optimal minimum value path among many alternatives.

3. Dijkstra's Algorithm and its Program

3.1. Dijkstra's Algorithm

Dijkstra's algorithm is called the single-source shortest path and is referred to as the standard shortest path algorithms. It computes length of the shortest path from the source to each of the remaining vertices in the graph. Dijkstra's algorithm solves the problem of finding the shortest path from a point in a graph (the source) to a destination. It can also be used for finding costs of shortest paths from a single vertex to a single destination vertex by stopping the algorithm once the shortest path to the destination vertex has been determined [14].

The input of the algorithm consists of a weighted directed graph $G = (V, E, w)$ and a source vertex s in G. We will denote V the set of all vertices in the graph G. Each edge of the graph is an ordered pair of vertices (u,v) representing a connection from vertex u to vertex v. The set of all edges is denoted E. Weights of edges are given by a weight function $w : E \to [0, \infty]$; therefore $w(u,v)$ is the non-negative cost of moving from vertex u to vertex v. The cost of an edge can be thought of as (a generalization of) the distance between those two vertices. The cost of a path between two vertices is the sum of costs of the edges in that path.

A path between two nodes v_0 and v_k is finite sequence $p = v_0 v_1 v_2 \ldots v_k$ of nodes such that for each $0 \le i \le k,\ v_i v_{i+1} \in E$, and the weight of the path is $w(p) = \sum_{0 \le i \le k} w(v_i v_{i+1})$.

The shortest path weight, also called distance, from node u to v, denoted $dist(u,v)$, is the minimum weight of all possible directed paths with origin u and destination v.

Let $u \xrightarrow{p} v$ denotes that v is reachable from u through the directed path p. We have formula:

$$dist(u,v) = \min\{w(p) : u \xrightarrow{p} v\} \tag{2}$$

For a source node $s \in V$, the shortest path algorithm calculates the distance $dist(s,v)$ for all $v \in V$. Suppose that S is a proper subset of V such that $s \in S$, and let $\overline{S}$ denote $V - S$. If $p = s...\overline{u}\overline{v}$ is a shortest path from s to $\overline{S}$ then clearly $\overline{u} \in S$ and the $(s,\overline{u})$-section of path p must be a shortest path from s to $\overline{u}$. Therefore the distance from s to $\overline{S}$ is given by the formula:

$$dist(s,\overline{S}) = \min_{u \in S, v \in \overline{S}} \{dist(s,u) + w(uv)\} \tag{3}$$

This formula is the basis of shortest path algorithm. Staring with the set $S_0 = \{s\}$, an increasing sequence $S_0, S_1, ...S_{n-1}$ of subset of V is constructed, in such a way that, at the end of stage i, shortest paths from s to all nodes in S_i are known.

3.2. Description of the Algorithm

Dijkstra's algorithm works by keeping for each vertex v the cost d[v] of the shortest path found so far between s and v. Initially, this value is 0 for the source vertex s (d[s]=0), and infinity for all other vertices, representing the fact that we do not know any path leading to those vertices. The following pseudo-code gives a brief description of the working of the Djikstra's algorithm.

```
Procedure Dijsktra (V: set of vertices 1... n {Vertex 1 is the source}
                Adj[1…n] of adjacency lists;
                EdgeCost(u, w): edge-cost functions;)
Var: sDist[1…n] of path costs from source (vertex 1); {sDist[j] will be equal to the length
    of the shortest path to j}
Begin:
Initialize
{Create a virtual set Frontier to store i where sDist[i] is already fully solved}
      Create empty Priority Queue New Frontier;
      sDist[1]← 0; {The distance to the source is zero}

      forall vertices w in V-{1} do {no edges have been explored yet}
           sDist[w] ←∞
      end for;
      Fill New Frontier with vertices w in V organized by priorities sDist[w];
endInitialize;

repeat
      v←DeleteMin{New Frontier}; {v is the new closest; sDist[v] is already correct}
      forall of the neighbors w in Adj[v] do
           if sDist[w]>sDist[v] +EdgeCost(v,w) then
              sDist[w] ←sDist[v] +EdgeCost(v,w)
              update w in New Frontier {with new priority sDist[w]}
           endif
      endfor
```

until *New Frontier is empty*
end*Dijkstra;*

When the algorithm finishes, d[v] will be the cost of the shortest path from s to v -- or infinity, if no such path exists. The basic operation of Dijkstra's algorithm is edge relaxation: if there is an edge from u to v, then the shortest known path from s to u (d[u]) can be extended to a path from s to v by adding edge (u,v) at the end. This path will have length d[u]+w(u,v). If this is less than the current d[v], we can replace the current value of d[v] with the new value.

Edge relaxation is applied until all values d[v] represent the cost of the shortest path from s to v. The algorithm is organized so that each edge (u,v) is relaxed only once, when d[u] has reached its final value. Dijkstra's Algorithm solves the single-source shortest path problem in weighted graphs. As a simple and consequently easily implemented algorithm, Dijkstra's algorithm depends on the data structures used to implement the graph representing the spatial network.

4. A Case of Emergency Response System

GIS is a powerful tool in the analysis and design of transport routing networks. Its graphical display capabilities allow not only visualization of the different routes but also the sequence in which they are built, which allows the understanding of the logic behind the routing network design [15]. A GIS analysis in emergency response is based on a spatial database which includes beside other data also geocoded addresses. The spatial database includes the traffic networks, administrative divisions, hazardous sites, hospital locations, population distribution, major public facilities, etc. When an accident was happened,emergency managers can easily obtain the required information on the hazard scenarios, find available resources in the neighbourhood, and evaluate the applicable response measures via the emergency response system for making decisions.

A Web service is a software system designed to support interoperable machine-to-machine interaction over a network. Web services provides a standard means of interoperating between different software applications, running on a variety of platforms [16]. GIS Web Services Services are discoverable, self-describing software components for making a reality of creating a platform independent distribution channel for GIS data. Applications can share data from different data sources and formats and have them combined in a single application.

Based on GIS web services, we developed a emergency response web application which was scripted in C#.NET, ASP.NET, JavaScript and HTML code. Microsoft Visual Studio was the programming compiler software. ArcGIS Server and ArcGIS Server Application Developer Framework (ADF) runtime were installed for the distribution of the web application. The web browser based clients could communicate with the web GIS service through the GIS web services. The clients perform URL requests to map service and obtain maps. A GIS Java applet is user interface that can be used to retrieve and handle the vector and raster map using the map tools

We use Ajax technology to access the spatial database. Ajax allows web pages to be updated asynchronously by exchanging small amounts of data with the server behind the scenes. This means that it is possible to update parts of a web page, without reloading the whole page [17]. A traditional web application user’s action triggers an HTTP request to a web server, which processes the request and returns an HTML page to the client. And additional requests lock up the application until the system updates the page. While Ajax applications create a JavaScript-based engine that runs on the browser. With Ajax, web applications can send data to, and retrieve data from, a server asynchronously (in the background) without interfering with the display and behavior of the existing page.

An integrated emergency response system is a decision support system that supports the emergency manager in planning, coordinating, and implementing rescue and assistance and other support operations during the response processes. In our emergency response system,the wab application contains tools to either select the Start/End location directly on the map. Shortest path analysis is used to analyze the shortest route between users’ defined origin and destination on the server, and its resultant route is rendered on top of the map service in graphical format using a map control graphics layer. Figure 2 shows the shortest path in the emergency response system. Emergency managers can use the shortest path function to search the rescue route and then determine quickly as to which rescue team should move to the accident location and which path should be followed.

The emergency response web application will display the accident location and relative information on map so that emergency command center can search this information instantly. The dynamic integration of web mapping services and information can provide more accurate and effective information for decision making processes.

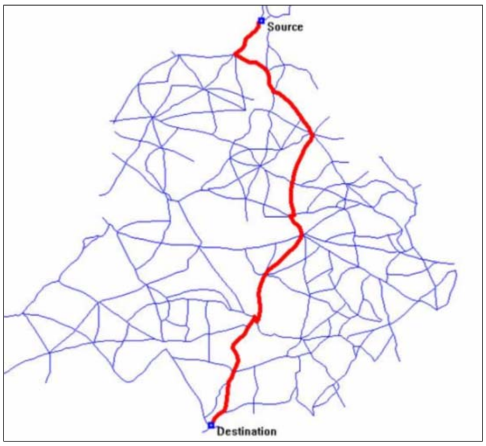


Figure 2. The Shortest Path in Emergency Response System

A well designed and comprehensive database is the prime requirement for a good network analysis. There are many extensions to the basic GIS data model needed to support shortest path analysis. We defined the length of the road to calculate the shortest path from one node to the target node in a map, and then select the optimal path among the road based on the minimum weight. In our emergency response system, the shortest path analysis do not consider other contributing factors (road width, speed limit, surface condition, and turn restrictions), which should be defined in the database to identify more realistic routes.

5. Conclusion

When an accident was happened, finding a path which takes minimum time to reach destination is important for rescue. Finding shortest path is not a solution all the time because there are several factors affecting travel time. The paper discussed the shortest path analysis based on Dijkstra's algorithm and implemented a emergency response system based on GIS,which can be widely used in all sorts of services that in any way handle sources and consequences of emergencies. Currently, the application provides the optimal route without considering road conditions and traffic congestion.Further research is focused on integrating this system with real time on-road traffic count to display more dynamic, reliable and accurate routes to emergency managers.

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