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DEVELOPING COMPONENTS OF WEB GIS FOR SHORTEST PATH ANALYSIS "FIND SHORTEST ROUTE": A GEOGRAPHICAL EXPLANATION FOR SSGC, PAKISTAN

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Abstract

The default web mapping application of ArcGIS Server lacks front-end support for Network Analysis. This paper presents an overview on the development of an ArcGIS Server based web solution for the evaluation of shortest path. The goal is to create an easy-to-use interactive vehicle routing mapping website which helps emergency response managers to find optimal routes and pass instructions to field crews through wireless or printouts during emergencies such as gas leakages. The principal development component includes: ArcGIS with Network Analyst, Visual Studio, and ArcSDE. The application includes: the ability to search addresses, landmarks, gas customers, gas installations and map optimal route with travelling time and distance.

Keywords: Emergency response, Web GIS, Route planning, Network analysis

1. Introduction

Sui Southern Gas Company (SSGC) is Pakistan's leading integrated gas company. The company is engaged in the business of transmission and distribution of natural gas in the southern provinces of Pakistan. Karachi city is the biggest region of its entire franchise area with an industrial, commercial and domestic gas consumer base of 68.90 percent (1,427,683) and distribution network is 41.47 percent (13,234 Km), for the 2007-08 financial year (SSGC, 2008).

Beside SSGC, Karachi city has the status of metropolis with an amalgam of economic activities. Most of the international trading activities either imports or exports operate through Karachi port that give way to massive freight movement along the port areas. Karachi holds more than 15 million inhabitants that sprawl over approximately 3570 square kilometers. The large spatial extent and dense population of the city provokes serious problems for emergency response agencies to route their vehicles towards incident sites. According to CDGK (2007), Karachi city is overlaid by approximately 9800 kilometers of road network that service about 1.5 million registered vehicles.

Everyday mobilization is largely affected by several factors including traffic congestion, rush hours, road condition, road width, driving speed and land use characteristics. In case of any emergency it is important to reach the location on a priority basis, and a minor delay may cause major problems. Shortest path analysis helps in such critical situations by calculating the *most optimal* route. Verbyla (2002) defined optimal routing as the process of delineating the best route to get from one location to one or more locations. The *Best Route* could be the shortest, the quickest or the most aesthetic, depending on the GIS user's preference for defining *best*.

Usually, nontraditional users are not part of GIS development teams; they require a lot of professional training to get specialized skills in order to use the traditional GIS software. Enterprise GIS is a platform for delivering organization-wide geospatial capabilities while improving access to geographic information and extending geospatial capabilities to nontraditional users of GIS. A well-designed customized interface helps users to use the GIS system more conveniently and efficiently.

SSGC started the development of a customized and interactive web application (*Find Shortest Route)* in January 2008 and completed it in July 2008 using its own GIS staff. This application allows emergency response managers to query and map the best possible vehicle route in the most convenient and useful manner with minimal operator involvement.

SSGC had developed the GIS base map up to household level information for its Karachi Region in 2006, completely in-house. The street centerline network layer has been used and modified as the backbone of the network dataset for use in the *Find Shortest Route* application. Other layers that are utilised in this application include: address/parcel information, point of interest (POI), gas customer locations, gas pipeline network and gas sensitive installations.

2. Web GIS

According to McDonnell and Kemp (1996), GIS is a computer system for capturing, managing,

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integrating, manipulating, analyzing and displaying data which is spatially referenced to the Earth. When compared with other available information systems, GIS is a step ahead as it offers spatial representation along with an embedded database to empower statistical analysis.

Tomlinson (2003) has described the functionality of GIS as completely storing spatial data with logically linked attribute information in a GIS database where analytical functions are controlled interactively by a human operator to generate the needed information product.

With the passage of time Web-based GIS is becoming more and more acceptable and practical. The World Wide Web (www) is a useful tool for gathering and manipulating information.

With the advent of Java and .NET based programming, software applications for web-based GIS work are now readily available. Some of these programs require the user to procure some software, and others require plug-ins to be added to web browsers, but some applications require no special software additions at all. These uses only the capabilities of existing web browsers through dynamic or cached map service.

The development of customized/out-of-the-box web base GIS applications is essential for enterprise level deployment of GIS; the main reason is the resource limitation either of the hardware/software or human expertise. A full-fledged GIS application requires massive input of resources, it is not possible to get several software user licenses or to purchase many high profile PCs as it requires heavy investment, moreover most of the end-users are not technologically strong as GIS developers. These short-comes can be covered by deploying web-based customized interface that is more convenient to use for all categories of users.

ArcGIS Server is a platform for building enterprise GIS applications and services that are centrally managed, support multiple users, include advance GIS functionality, and are built and delivered using industry standards. ArcGIS Server provides the framework for developers to create focused GIS Web applications and services that can be utilized by clients including Web browser-based applications, the ArcGIS Desktop products (ArcInfo, ArcEditor, and ArcView), and ArcGIS Engine applications.

The ArcGIS system is based on a common library of shared GIS components called ArcObjects. ArcObjects include a wide variety of programmable components ranging from fine-grained objects, such as individual geometry objects, to course– grained objects.

3. Role of GIS in network analysis

Geography matters a lot when decisions are spatial in nature as Antenucci *et. al.,* (1991) elaborated that GIS is emerging as a tool in the transportation industry, as well as in industries that involve logistics or use transportation services. Applications include vehicle dispatch and fleet management. Longley *et. al.* (2005) discovered that effective spatial analysis requires an intelligent user, not just a powerful computer. A GIS and spatial analysis can be very effective at solving routing problems because it is able to examine vast numbers of possible solutions from various perspectives with speed and accuracy.

The acronym GIS-T is often employed to refer to the application and adaptation of GIS to research, planning and management in transportation. GIS-T covers a broad arena of disciplines of which road traffic incident detection is just one theme. Others include in vehicle navigation systems (Anderson, 2003). Emergency routing systems are mostly GIS based and are effectively implemented in several developed cities of the world.

The traditional conventional methods of transportation analysis involve intensive time and labor, and computer based systems lack human perception that may result in inefficient solutions. 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. In case of any incident, the emergency response officer needs a smart decision support system to reach the incident location as soon as possible.

The shortest route analysis available with several GIS software serves the purpose well, but it only considers the ideal situation. The particular details about the road environs and other contributing factors (road name, width, speed limit, surface condition, one-way and turn restrictions) should be defined in the database to identify more realistic routes. A well designed and comprehensive database is the prime requirement for a good network analysis. Miller and Shaw (2001) stated that in a review of various data models needed to support transportation analysis, there are many extensions to the basic GIS data model, such as turn tables, dynamic segmentation, route planning, milepost schemes and traffic lanes.

Feature information available in attribute tables builds the logic for network analysis, for example the speed limit stored as attributes defines the fastest route, which may not be the shortest (in terms of length). Other attribute information builds optimum driving directions for the driver. The major factors involved in network analysis are; cost (length), description (road type), restriction (turns, speed limits), hierarchy (road level), parameter (defined set of rule) and direction.

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 (Gupta *et. al*., 2003). GIS can be applied to any service that is dependent on a network such as water supply, power supply, sewage, etc. Therefore, it could also be of great help for transportation engineering and planning. When so many parameters are to be connected with transportation network like travel time, speed, road resistance, turning movements, etc, GIS proves itself as an efficient tool for solving such network problems quickly and with great precision (Advani *et. al*., 2005).

4. Web application GIS data

Following geographic data has been used in the web based routing application:

i) Existing SDE transportation street centre line data of Karachi that provided the backbone for the development of final network data.

ii) Point of interest (POI)

iii) A comprehensive GPS survey has been conducted for the collection of approximately 40,000 POI for the city of Karachi, which mapped various city landmarks (like universities, colleges, parks, schools, hospitals, restaurants and shopping centers etc)

iv) Gas consumer/customer locations Gas pipelines

v) Gas installations

vi) Address layer/parcel data

vii) SPOT 2.5m high resolution (2m) satellite data as backdrop

5. Building network dataset

A network is a line coverage, which is topology-based and has the appropriate attributes for the flow of objects, such as traffic. The geometry of a network can be digitized or imported from existing data sources. A network, however, must have the appropriate attributes for real-world applications. The attribute data for road networks includes impedance values assigned to network links, turns, one-way streets, and overpasses and underpasses (Chang, 2002).

Attributes associated with the network's links, such as length, travel speed, restrictions on travel directions and level of congestion, are often taken into account. The path that is strictly shortest is often not suitable, because it involves too many turns or uses too many narrow streets, and algorithms will often be programmed to find longer routes that use faster highways, particularly freeways (Longley *et. al*., 2005).

Lapalme (1992) described the sensitive spot in route planning as the design of algorithms, but other activities are also implied, finding the location of the clients, computing the distance between them, evaluating their service time, and managing the fleet of vehicles. When all data are collected and when the objectives are well defined, an appropriate algorithm is run.

The development for the routing network dataset for the city of Karachi was accomplished in house by SSGC GIS staff. SSGC had no existing network dataset and the existing road network required several changes to use it as a network analysis dataset. The existing layers lacked fine-tuning such as all road segments did not breakup at intersections or had connectivity problems. These fine errors were removed before building the network dataset as any disconnection or unwanted continuity may cause great errors in shortest route calculations.

Network data preparation involved the following steps:

i. The planarize tool was used to breaks line segments at each intersection and remove duplicate segments.

ii. Fine errors are controlled and removed through ArcSDE topology processes. Topology is the term that refers to a set of rules to define and control how each feature will be drawn in a map or how it will connect with other features. Undershoots in the dataset were removed by defining tolerance value (radius for snapping purpose), while building topology. The following topology rules are applied to the road feature class to check and remove fine errors;

- Must Not Self Overlap *(remove loops or overriding in same line segment)*
- Must Be Single Part *(make sure that each road have a single line segment)*
- Must Not Self Intersect *(remove overlap or intersection in same line segment)*

iii) An ordinary road netwo*rk that is being used in base maps contains a single* line (centre line) for each road and there are no pre-defined restrictions like one-ways and turns. Before creating the network dataset, all roads were carefully marked with one-way, and turn restrictions.

iv) Overpass and underpass modeling was accomplished by the use of inserting a vertex on a linear feature where connectivity was desired and removing the vertex at the intersection of two line features where connectivity was not acceptable.

v) The most difficult task was to demarcate newly constructed roads, bridges and underpasses on the satellite image (because the satellite data was slightly older). A GPS survey was adopted to mark all such recent developments.

vi) Once the features were constructed and aligned properly, the next phase was to add and update their attributes to supply necessary information for analysis which included:

- Road classification
- Road naming, if available
- Road directions (one-way or two-way).
- Mean road speed for vehicles.

The ArcGIS interface has pre-defined logic that has capability to extract relevant respective information from the database, if the attribute table contains specific fields defined by logical names like hierarchy, one-way, felev/telev (from elevation to elevation) they are automatically added to the network analysis while building the network dataset. More specific rules can be applied by defining parameters in the network dataset that control user defined queries and calculate the shortest path according to the parameters.

Any network analysis requires impedances associated with each road in the network. By which we can give priorities to the different roads for analysis. Such impedances are very important in optimal route determination. At the junction point of roads, resistance occurs due to turning or due to interferences of other vehicles. How much delay will occur due to such an intersection depends on the movement of the vehicles. By assigning all information to a GIS network and performing a network analysis gives the optimal route with the information about the direction, time required and length of each segment of the road as well as the total length and time for the route (Advani *et al*., 2005).

6. Find shortest route web application development

Heavy server/thin client was implemented using distributed architecture for *Find Shortest Route* web application. According to Peng and Tsou (2003), the most common versions of distributed architecture are the three-tier software architecture for system implementation.

The first tier is called the client tier and includes a user-wide web-browser and user resident Java applets/ HTML documents. Users interact with the client tier via a graphical user interface (GUI). The primary function of the client tier is to accept user's data requests and to display the results. The second tier, called the middleware tier, includes the Web Server and the Server connectors (such as Servlet connectors or Active Server Pages- ASP connectors), which bridge the communication between clients and the server. The third tier is the data storage tier, which includes the Database Server. The three-tier software architecture can be deployed on different hardware configurations (Jankowski *et. al.,* 2008).

The specific implementation of the three-tier architecture for *Find Shortest Route* application was comprised of the client (web browser), the GIS Server and the database as illustrated in (**Fig. 1).** The architecture in Fig. 1 implements the concept of *server-side* processing and a thin client.

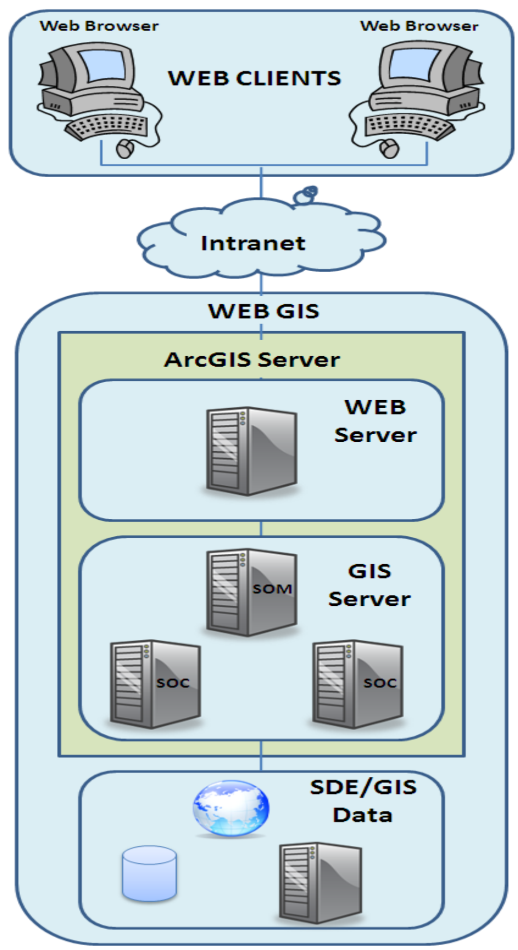

Fig.1. Three tier architecture of "Find Shortest Route"

6.1 Web application interface

The default web mapping application of ArcGIS Server lacks front-end support for Network Analysis. A panel with a GUI was added to the *Find Shortest Route* webpage which contains tools to either select the Start/End location directly on the map or type-in the Start/End address in textboxes **(Fig. 2).** Several graphical layers were added to map control of routing application. These layers were used to draw graphics depicting Route, Start and End flags.

Fig. 2 "Find Shortest Route" - Web application interface

The *Find Shortest Route* application also utilizes ASP.NET 2.0 CallBack Framework. According to ESRI's Developer Network online help, v9.2, ASP.NET 2.0 implementation of client callbacks uses the Client Callback Manager to provide an extensible callback framework. After initial page load, subsequent requests to server-side code are made by a client-side component, without refreshing the entire Web page. The Network Analysis panel also uses this CallBack Framework to reduce full-page postbacks to the server. This enhances user experience and reduces response time.

The main components of the Find Shortest Route interactive web vehicle routing site include:

i. The ability to search shortest route by giving origin and destination location from any of the following layers.

- Address/Parcel layer
- Point of interest
- Gas customer/consumer location
- SSGC's offices locations
- Gas installations

Standard codes have been used for the identification of layers in the origin and destination input box. Origin and destination layers could be different.

ii. The ability to search shortest route by giving origin and destination directly on the web map.

iii. Result is shown in the form of textual driving directions accompanied by vector graphics on the map control. Driving directions include turn-by-turn information (including POI along the route) and length of each segment and the mean time taken to traverse. Users can change the unit of distance used, by default it is in miles but other units such as kilometers, meters, feet and yards are also available.

iv. The ability to print full length of optimal route in a map window along with an overview map window, start and end position at a scale of 1:1000 and driving directions in table format.

v. The ability to provide zooms in and out, panning, feature identification and length measuring facility.

6.2 Web application deployment components

The *Find Shortest Route* web application for mapping and routing interface was scripted in C#.NET, ASP.NET, JavaScript and HTML code. Microsoft Visual Studio was the programming compiler software. Web Server (Microsoft IIS), ArcGIS Server with Network Analyst Extension and ArcGIS Server Application Developer Framework (ADF) runtime were installed for the distribution of the web application and services through a dedicated HP Proliant DL380 G5 Series dual processor and 4 GB RAM.

6.3 Preparing data for web application

ArcGIS Server services form the core of *Find Shortest Route* web application. Two ArcGIS Server web services were used for the application to function. First is a Map Service, which served the purpose of displaying a map for the city of Karachi. A map service provides access to the contents of ArcGIS map documents (like .MXD files). Second is a Network Analysis service of the network dataset. This solves transportation network analysis problem using the Network Analyst extension of ArcGIS Server.

Map Service display of Karachi needed caching due to the sheer volume of data it handles. There were two types of cached map services, single fused cache or a multi-layer cache. For optimal performance, a single fused cache was used for the *Find Shortest Route* web application. A single fused cache contains image tiles that are created by flattening all the layers in a map document into several large images. Applications built with fused caches do not use the parent map service, but instead pull the images directly from the cache directory or by using the tile handler service. Cache generation and display is also completed more quickly in the fused cache option.

The Network Analysis service uses a network dataset created in ArcGIS Desktop. The Network Analysis service layer is not displayed in the *Find Shortest Route* web Application. Instead, it 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.

No standard address style/standard existed for Karachi, in spite of it being such a large and spread out city. Most streets are unnamed; citizens mostly use nearest landmarks to explain addresses. Therefore, an addressing standard representing *Full Address* was created in a single field in SDE data which were then used for creating address locators using a single field ArcGIS locator style. This partially provides searching of addresses but it is only effective when users enter addresses in exactly the same format as it is entered in the full address field.

7. Conclusion and future prospects

This research work is a result of the activities undertaken by Sui Southern Gas Company Limited for better emergency response in case of gas leakages or customer complaints by finding shortest possible routes through a web base GIS application. Currently, the application provides the optimal route without considering road conditions and traffic congestion. During an emergency, application operators can pass instructions to emergency responders through wireless or printouts. The application also does not provide a facility to identify emergency vehicles nearest to an emergency location, but it has been planned to incorporate an emergency vehicle tracking facility in future in the same application.

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