CRP-514: Geographic Information System

Term Paper

Title: Applications of GIS in Transportation and Route Planning

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Abstract:

Transportation systems serve as the backbone and life line of the economic activities of any society. They consist of roads, airports, seaports, railway stations and other modern means of transport. The decisions regarding any new or improvement projects involve a lot of investment and affect many disciplines of the society in one way or the other. Often these decisions are taken on political basis by the people who are not experts of this field. In order to facilitate their decision making process and ensuring the transparency of the investments; GIS becomes a good and perhaps the only platform to convey, analyze and represent the information to the administrating and planning authorities. With the present growth in the area of intelligent transportation systems (ITSs), GIS also provides a very good interactive framework to convey real-time traffic information to the road users. These types of interactive systems help the users to select their routes according to the prevailing conditions of traffic.

At present, there are many going on around the world in the area of research, planning and maintenance and operation of transportation systems, in which GIS in being used. In this term paper I intend to firstly; establish the need of GIS for transportation engineering and secondly; summarize the use of GIS in different projects in works related to transportation and route planning.

1. Introduction

Transportation systems represent the most important infrastructure for a country; it is also the most difficult geographic feature to work with. The analyses of these systems require diverse data items in a considerable amount including;

- Household
- Demographics
- Land-use
- Social and commercial activities
- Etc.

All these data items affect the demand and use of transportations systems equally and hence requires a multi-dimensional approach for the development and analysis of transportation projects (Xie et al, 2000).

Geographic Information Systems

GIS systems provide transportation planners with the most suitable platform for their application as it can accommodate multiple-layers of data for the different geographic locations and provides different tools for its analysis, editing and display (Al-Ramadan, 2005).

Geographic Information Systems (GIS) is the name given to the specialized computer programs which are developed to analyze geographic information with flexibility. They include the following (Bernhardsen, 2002):

- Input geographical information in digital format
- Storing information in compact format
- Automated analysis of geographic information involving defining and identifying patterns, making measurements and the like
- Prediction of outcomes of various scenarios
- Display of data in various formats
- Output of display in numeric and tabular formats

2. Aim & Objectives

GIS is applied by many transportation engineering professionals for different applications; mainly due to its ability to accommodate multiple-layers of data and flexible and integrated representation abilities. This paper presents the literature and case studies that explains the above trend. Its main objectives are the following:

- Explain the need of GIS for transportation engineering
- Summarizing the use of GIS in different projects in transportation engineering sector specially in works related to transportation and route planning

3. Methodology

The methodology follows the steps given below:

- Literature review including:
    - An introduction to transportation engineering and GIS
    - Need of GIS for transportation planning
- Finding out case studies that involve use of GIS for transportation engineering sector
- Presenting a brief description of case studies including the specific need to use GIS in the particular project
- Discussing the trend of use of GIS for transportation projects and the complexities and advantages involved its implementation

- Concluding the paper with recommendations regarding further use of GIS in the industry and the areas to focus/improve

4. Literature Review

GIS is considered helpful in many fields because of the following advantages (Al-Ramadan, 2007):

- Integrating geographic information display with the analysis data framework
- Allowing manipulation and display of geographic information for depicting scenarios as a result of different decisions taken
- Automating map making and updating
- Integrating geographic information with feature attributes
- Offering different layers of geographic information
- Providing a unified database for multiple users

4.1 GIS in Urban Planning & Services Planning

Although GIS has been applied extensively in the fields of computer sciences, cartography, photogrammetry, surveying, remote sensing, geography, hydrography, statistics and information sciences; but with reference to the subject of this paper a few examples related to the field of planning are being given. More emphasis has been given on its application to the field of transportation engineering.

- **Planning and Development**

Escalating construction costs have been catalyzing the optimization of building and road locations in order to minimize blasting and other earthwork costs. The plans should be flexible and easy to interpret as the decisions are being influenced by various social interest groups and citizens. GIS provides a simplified environment to visualize the impacts of any decision being made.

- **Land Management**

Computerized land registers are playing a vital role in restructuring the system of land ownership in many developed and developing countries. These systems help to get the overview of the property for the purpose of taxation, loan security and other economic analysis. GIS based-land registers are able to process a large amount of information and hence speeding up the decision making process.

- **Safety at Sea**

In recent years, the volume of sea transport has increased alongwith the installation of oil rigs and other under-water and off-shore fixed facilities, which increases the problems regarding safe navigation. New GIS-based technologies enable the information to be sent to mariners via public telecommunication networks combined with electronic charts and positioning and radar displays, hence improving the safe sailing of the ships in hazardous waters.

- **Military Uses**

Modern military training and operations have become highly computerized and most of the modern military computer programs are based upon GIS platforms. Digital geographic data representing the precise location and form of lands is used for flight simulation and missile navigation and also for the modern drone technology.

4.2 GIS Technology for Transportation Planning and Traffic Engineering

Transportation sector has been a heavy consumer of maps and other geographical data, so the use of GIS in this sector enables the integration of technical and geographic data which results in considerable savings in time, money and man power (Bernharsen, 2002). Transportation engineering is of a multi-dimensional and complex nature. The following paragraphs explain the use and need of using GIS in different areas and stages of this sector.

- **Intelligent Transportation Systems**

The traffic conditions have become very complex, especially in urban areas in terms of congestion and safety. To address these problems, Intelligence Transportation Systems (ITSs) have been the focus of many research efforts in this area. These systems are based upon timely and precise dissemination of information to the user which can be most appropriately achieved through a GIS based technology; that may be web based for the accessibility of the road users. In- vehicle tracking (Also known as Location Based Service; LBS) and navigation technology, which has wide-spread use now a days, is a simpler version of modern GIS technology providing the user with simple maps and other basic supplementary information (Bernharsen, 2002). With the centralized storage of the data of these trackers, they can serve as a real-time data input to the intelligent transportation systems as well as a valuable database for long term evaluation of the system.

- **Traffic Safety**

Traffic accidents are a result of a number of factors that may include road geometry, weather conditions and other exogenous factors as well. With the help of GIS it is possible to

incorporate a variety of data into the analysis of accidents of a particular sight and search for the pattern or combination of factors having more influence on the situation.

- **Transportation Network Expansion Projects**

Transportation networks and regional development complement each other, sometimes the networks are established to connect the land parcels and in other times the land parcels develop because of the ease of access to the area. This also results in changes in the property values. Hence, it is clear that regional development and road networks grow synergically and requires input from both fields for regional development and road expansion projects. GIS is used as a framework to analyze the impacts of development in one sector on the other.

- **Environmental Impact Assessment**

Transportation projects influences the environment and the physical surroundings greatly. In order to quantify and minimize these effects, an Environmental Impact Analysis (EIA) is done for assessing the impacts of transportation projects environment and atmosphere. It involves a multi-dimensional approach involving environmental contaminant data as well as traffic and other project-related data. GIS with its multi-layer environment incorporates all the data needed for analysis and also helps in impact studies (Alagan, 2007). In addition to that, the road and vehicles also interact with the surrounding wildlife which may also involve endangered species; in that case certain adjustments may also be needed in the road alignment or enclosing of the area to avoid vehicle-wildlife collisions (Gunson et al, 2010).

- **Multi-Modal Planning**

The complexity of the integration of the roads, railways, waterways and aviation, there is an enormous amount of options involved for the users interconnecting these modes. A multimodal network (MMN) is a transportation system that considers two or more transport mode choices for connecting locations (vertices) in a network (Xie et al, 2000). Freight and urban transportation are two application fields in which multimodal networks are extensively found. In freight transportation is thoroughly reviewed for identifying possible research trends (Lillo et al 2010). GIS also presents the users with lots of abilities to solve multi-modal networking problems; such as (Xie et al, 2000):

- Identifying possible alternative routes between points
- Identifying the best route between many points
- Identifying the closest facility to a location.
- Drive time analysis.

The real-time travel information dissemination when combined with historic traffic information can be very useful for routing strategies, for that web-based GIS is the most appropriate tool (Alazab et al, 2011).

5. Case Studies

In the following sub-sections, some case studies are presented in which GIS is used in transportation engineering with special focus on transportation routing and planning problems.

5.1 Use of TREX for User Information by Georgia Department of Transportation, USA

Georgia Department of Transportation started its GIS initiative by ITS Navigator; an ArcInfo based GIS application used to provide real time information to the users about traffic congestion, highway incidents and construction activities. This was done as a part of preparation for 1996 Olympics hosting an influx of more than 2 million visitors. With the success of that initial application, GDOT expanded its use of GIS by digitizing its paper maps and data and contributing in establishment of a state-wide base map.

With the increasing amount of data and diversified work force of about 4000, GDOT set its sights on creating highly visible and easy-to-use applications that made using GIS as easy as using the Internet. To build support for such an undertaking, GDOT implemented a pilot project called Transportation Explorer (TREX). Based on ArcIMS, TREX was designed as a Web application that allowed the public to search GDOT maps, reports, and plans for all transportation projects in Georgia.

The needs assessment, presented in 2005 to the GDOT enterprise team by ESRI professionals, identified seven enterprise GIS initiatives, including Mapping on Demand, a system to provide non-GIS users with the ability to create, modify, and print user-defined maps in multiple formats. Mapping on Demand became phase 1 of GDOT's enterprise GIS implementation, and it was accomplished by engaging ESRI Professional Services to completely redesign the TREX architecture framework to work with ArcGIS Server 9.2 Java Application Development Framework (ADF) for ArcIMS and ArcGIS Server.

The redesign of TREX has not only helped to deliver services and information for the departmental use of GDOT but also has increased the public participation enhancing the transparency of their work. That is a mutually beneficial outcome for both GDOT and the traveling public. TREX proved the benefits of adopting enterprise GIS architecture and paved the way for further implementation. During the past five years, GDOT GIS has grown from 60 GIS desktop product users to more than 12,000 users (including the public) of GIS data and services. GDOT plans for further investments in this area to reduce cost and time of transportation projects in planning and design phases. In addition to that, extending multiple

GIS services from central offices to statewide field/mobile operations are in the planning process (Arc News Spring, 2007). Figure 1 shows results from a project search can be seen in the map view and results pane with icons that provide access to external project reports.

Figure 1: Search Results from TREX
Source: ((Arc News Spring, 2007, pp. 1)

5.2 Determination of Optimal Paths Using GIS for Multi-Modal Networks of Europe and New Zealand

Lillo et al (2010) used the GIS data for determining optimal paths for multi-modal networks in Europe and New Zealand. They carried out an appraisal to analyze the manner of the shortest path problem in real MMNs. Their employed modeling approach takes a colored–edge graph that represents modes, cities and intercity links by colors, vertices and edges.

The colored–edge graph is a modeling tool introduced for the modeling of MMNs. For a real transportation system colored-edge allows multiple edges between two points for different modes. In this research weighted colored–edge digraphs were utilized to model real multimodal transportation networks from several countries.

The experimental study collected vector data information about Denmark, Hungary, Spain, Norway and New Zealand from a GIS library. The countries with similar shapes and sizes were selected. For example, New Zealand resembles with Norway in shape and number of vertices. Both countries have long shapes and range between number 100 and 200 for locations.

The multimodal networks were represented by a set of vertices and bidirectional links. A network was made by connecting vertices i.e. towns and cities by snapping on to them. Then, a connectivity map was created by an ad-hoc algorithm that iterates itself through vertices. The algorithm also calculated the distances between vertices based upon their geographic coordinates. Airways were also added as a third mode for Norway and New Zealand. For snapping airports to cities straight distances between airports were used as edge length in this case to cities to build a connectivity map. Airway data was obtained from OpenFlights 2010. The following table presents the nature of resulting networks.

In their study, they were able to study the shortest paths connecting different cities incorporating different modes. They were also able to find out the similarities and differences between cities' transportation networks and the reasons for them. GIS provided them with a visual interpretation of the connectivity of different cities and their modal characteristics (Lillo et al, 2010).

Table 1: Network Characteristics
Source: (Lillo et al, 2010, pp. 284)

Network	Country	Vertices	Edges	Modes
1	Denmark	124	1284	Road,Rail
2	Hungary	305	7418	Road,Rail
3	Spain	901	5326	Road,Rail
4	Norway	122	641	Road,Rail,Airways
5	New Zealand	183	1436	Road,Rail,Airways

5.3 Transportation Routing Problem in Al-Zarqa City Jordan

Road users are often faced with the issue of choosing the best route for vehicles, especially when it is time dependent. It has been a critical matter in the transportation routing problem because it involves cost, manpower time and service quality. The shortest path is often mistaken for the shortest distance measured, without considering other conditions such as road congestion that might delay arrival of the vehicle. Sometimes a path with longer distance may take lesser time to reach the destination because of less traffic congestion. In this study, GIS was used to thoroughly analyze this problem.

Using GIS, we can use the real-time information gathered about the dynamic changes in the traffic flow to serve as the typical constraints to solve a routing problem in a stochastic transportation network. Alazab et al (2011) proposed an optimal transportation routing algorithm that caters to these constraints. The authors presented a systematic approach to aid in the implementation of their proposed algorithm for an efficient road transportation routing system integrated with a GIS to provide real-time traffic flow information. In their study, they considered a stochastic shortest path problem on a road network, which composed of links with nonstationary travel times, where subsets of these links are observed for traffic flow in real-time with the aid of a GIS. An assumption was made that each observed link can be in either congested or uncongested state based on the travel time distribution used in their algorithm.

They studied the traffic system in the busy and well-known Zarqa city in Jordan, and the data was collected from its geographic information center (GIC) over a period of two weeks. Table 2 shows the 15-min data of average speed of a vehicle throughout a day based on distance and average congestion. For each intersection the distance between edges was calculated with the aid of a digitizing map and they represented this information as graph containing intersections (nodes) and roads (arcs).

Table 2: Average Speed Data

Source: (Alazab et al, 2011, pp. 174)

	Loop number	0:00-0:15	0:15-0:30	0:30-0:45	0:45-1:00	…..	12--12:15
Day 1	1	73	72	72.9	73.82		74.2
	2	59.12	60.21	60.9	59.7		61
	..	..	..	..	..	..	..
Day 2	1	72.02	71.2	71.9	72.3		73.9
	2	60	61	62.2	61.9		61.82
	..	..	..	..	..	..	..

For depicting the road network of the city a real-time map with the Geographic Information System (GIS) was used to generate the network depicting the road transportation network of the city. They converted these maps to the digitized form using digitizing converters, which store them as digital raster files. Then a "raster-to-vector conversion was done by importing these files into ArcCatalog, to have the final output in a vector format, containing specific information such as streets, blocks, and addresses.

The address layer of point shapes and block layer represented by polygon shape were stored in the database as shown in Table 3 with properties, such as: i) FID as the index of block / point with unique values, ii) Shape that refers to the shape type of this instance, iii) S_N that refers to the street name of the block or point, iv) B_B_NO as the base block number, and v) S_B_NO as the sub-block number. These vectors were used to generate the network of nodes and arcs that would serve as an input to the proposed shortest path algorithm and finally for drawing the shortest path output.

The resulting GIS was implemented within a web application for enabling the users to discover optimal paths for their trips and provide driving directions between two nodes on a GIS based digital map. A screen snapshot of the Web application thus created is shown in Figure 2 (Alazab et al, 2011).

6. Discussion

The above case studies presented some useful applications of GIS for transportation planning and route selection. GIS becomes a much more helpful tool for use when integrated with a web application to provide easy access and real time information to the users, as was done for

GDOT and Zarqa city. This would in turn facilitate traffic management by increasing driver's awareness of road and traffic conditions. Another important thing to note is the dominance of ESRI in this field, GDOT and Alazab et al in Zarqa city, both used their expertise and product for their specific application. ESRI also helped as a consultant to GDOT for preparing TREX, which is another evidence of their expertise in this field.

Table 3: Polygon Properties

Source: (Alazab et al, 2011, pp. 175)

FID	Sshape	S_n	B_b_no	S_b_no
0	point	Saqer	2	1
1	point	Karamah	2	1
2	point	Saqer	1	1
3	point	Perin	1	2
4	point	Perin	1	2
5	point	Saqer	4	2
6	point	Saqer	4	1

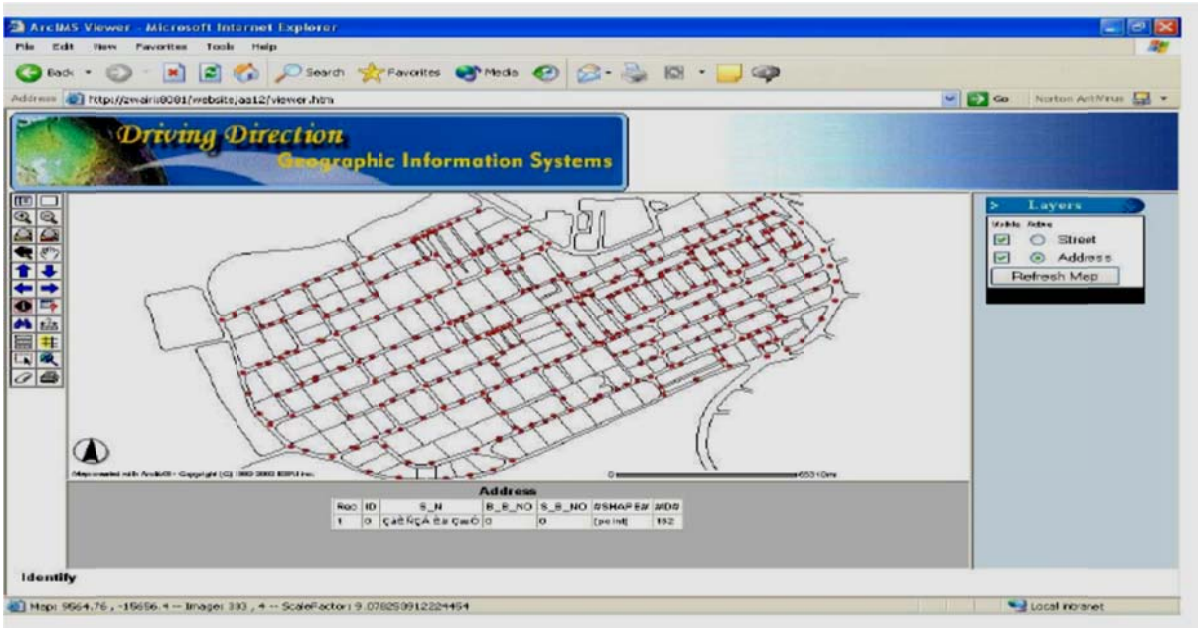

Figure 2: Web-Based Vehicle Routing GIS

Source: (Alazab et al, 2011, pp. 177)

GDOT used the GIS system initially to solve the problem of traffic management and in the end extended its application for the planning and monitoring of the whole system of road networks under their jurisdiction. This web based GIS application helped to improve their coordination of the construction and maintenance activities, enhanced the accountability and transparency of their work and increased the awareness of users about the road networks and its activities.

Lillo et al studied the optimality of different modes of transport between different cities of Europe and Switzerland. By using the colored-edge graph on a GIS map they were able to represent different modes connecting the two cities. By using this technique they were able to address the complex issue of route planning with multiple modes connecting two cities. This was possible because of the ability of the system to incorporate different layers of data and analyze and represent them on a single map.

In the study for Zarqa city, Jordan the web based GIS application provided the users: the ability to find the optimal path between two points by dynamic generation shortest path, access to an integrated display of traffic flow data generated from GIS services and assisting the vehicle drivers with a Web interface for navigation on the digital maps (Alazab et al 2011).

Although all these studies present a very broad spectrum for the use of GIS services in the area of transportation planning; a few issues have to be addressed before the effective implementation of any such system. These include:

5 Data gathering which consists of paper maps to traffic data and road geometric features
6 Digitization and data formulation to be viable to input in the system, which includes digitization of maps to classification of road and traffic features
7 Allocation of a dedicated team for updating data and system
8 Acquisition of in-house expertise for long-term application and maintenance and consistent updating and improvement of program
9 Coordination of experts from different fields including GIS developers, data collectors and surveyors and transportation engineers to specify the goals, objectives and scope for the system

7. Summary and Conclusion

Transportation systems represent the most important infrastructure for a country; it is also the most difficult geographic feature to work with. GIS systems provide transportation planners with the most suitable platform for their application as it can accommodate multiple-layers of data for the different geographic locations and provide different tools for its analysis, editing and display. Transportation sector has been a heavy consumer of maps and other geographical data, so the use of GIS in this sector enables the integration of technical and geographic data which results in considerable savings in time, money and man power.

The above case studies presented some useful applications of GIS for transportation planning and route selection. GIS becomes a much more helpful tool for use when integrated with a web application to provide easy access and real time information to the users, as was done for GDOT and Zarqa city.

At the end, we can conclude that GIS can be and should be used for almost all the applications regarding transportation planning. It can help the experts to understand and analyze the problems in a better way, while it also adds to transparency and accountability to the decision making process. In transportation systems, decisions are often made by managers or politicians who need to see the effects of their decisions on the environment and society. GIS with its dynamic and multi-layer environment provides them with the solution. With the advent of web-based GIS, it has become possible to incorporate the real-time information about traffic, roadway and weather situations. It makes GIS a very good tool for Intelligent Transportation Systems (ITSs).

However, some issues need to be addressed before GIS can be implemented for any transportation-related application. The first one is related to data, geographic and attribute data are the back-bone of any GIS map, which may or may not be present in digital format. Digitization of data in the format which is applicable to the particular often requires appreciable amount of resources and time. Secondly, it's the updating of the data to make the system sustainable for longer periods of time; it will require a dedicated team of professionals for gathering the data and update the system.

Acquisition of the required expertise is another issue which hinders the adaptation of GIS in many organizations as the hiring of expertise on contract basis may not prove economical for continued operations. Hence, organizations have to arrange for training and education before starting operation of their own GIS system. As with the implementation of any new system; the coordination between different departments of organization is of utmost importance for its getting the desired benefits out of the system. The same case is also there for GIS and its application.

The above discussed factors; are the possible obstacles for the application of GIS in the field of transportation planning.

Note: The case studies presented in the literature are all attached in the appendix.

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Appendix – Case Studies