GIS Applications in Transportation Analysis and Planning

(Final Term Paper)

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Abstract

Over the years, Geographic Information Systems (GIS) technology has been implemented for a variety of purposes within the transportation industry. With this have come many new uses, benefits, and challenges. This paper tried to show the capacity of GIS to support transportation analysis and planning. Section one introduces the deployment of GIS since its development and its major impact on transportation analysis. Section two is stating the main objectives of this research. Section three describes the methodology carried out to conduct this research. Section four provides a literature review of basic concepts of GIS and some publications about GIS applications in transportation and new GIS technologies used in these applications. Section five provides examples of how GIS is being used in practice in transportation analysis and planning through summarizing two published case studies. Finally, section six suggests some recommendations for future studies.

Understanding the basic concepts of GIS is a good start of the literature to allow the people who do not have an idea about GIS to know what GIS is. Internet is a very rich source of published papers, journals and technical reports to explore some published works about GIS applications in transportation analysis and planning (GIS-T). Also, the technologies used in this area such as using internet GIS in transportation is also reviewed. The contribution and the practical application of GIS in transportation field is reviewed through two case studies. One of those case studies is local to show to which extent GIS application is used in transportation sector in K.S.A, particularly in Riyadh. Each case study is followed by a discussion of the main findings of each study. Recommendations are suggested to improve the GIS applications in transportation analysis and planning. As a result, there is a broad application of GIS in transportation. On the other hand, there is a lot of value to GIS that is not yet being fully explored in transportation analysis and planning.

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1. Introduction

The GIS is one of the most innovative advances in the study of geography. Since its development in the 1970s, GIS has had a major impact on geographic analysis and on business practice in government and the private sector. Most transportation agencies now use GIS and Geospatial Information Systems for Transportation (GIS-T) is one of the largest users of GIS technology. The significant innovation that GIS provides is the ability to manage data spatially in layers and then overlay these layers to perform spatial analyses. Therefore, a roads layer can be integrated with a land use layer enabling a buffer analysis of the land uses within a given distance of the road. The capabilities of GIS have improved over the past three decades, and GIS now provide a wide range of tools for data management and analysis. In the early 1990s, GIS added specific tools for linear data management of transportation data that has proved to be extremely successful among transportation organizations. These capabilities enable transit agencies to georeference their bus routes, stops, time points, and other features to a digital street centerline file, and keep all these data in synch (Sutton *et al.* 2004).

The deployment of GIS has attracted the interest of transportation software vendors who provide scheduling, vehicle tracking, and trip itinerary planning programs. In some cases, these vendors have developed their own mapping interfaces with GIS-type functionality. In other cases, they provide import and export programs to convert data into compatible GIS formats. These developments reflect in part the demands from the customers for mapping inter-faces.

Another interesting trend has been the convergence between geospatial technologies comprising GIS, GPS (global positioning system), and remote sensing technologies such as satellite images, LIDAR (Light Detection and Ranging), and products that orthorectify remote sensed data. This convergence is occurring in part because of IT compatibility and the overlap and complementarities between the technologies. Many users prefer the term “geo-spatial” to “geographic” information systems for these reasons (Sutton *et al.* 2004).

2. Objectives

The main objectives of this paper are:

- To give an idea about the elementary concepts of GIS such as definition of GIS, Benefits of GIS, Urban applications of GIS, levels of GIS, and so on.
- To review GIS applications in transportation analysis and planning and to review the technologies used in this area such as using internet GIS in transportation.
- To show the contribution and the practical application of GIS in transportation field through some case studies and discuss the main findings from each study.
- To suggest some recommendations to improve GIS application in transportation analysis and planning.

3. Methodology

The steps are as follows:

a. To understand the basic concepts of GIS. It will be wise to go for elementary books and papers like those covered in our classes. This is a good start of the literature to allow the people who do not have an idea about to GIS to know what GIS is.

b. To explore some published works about GIS applications in transportation analysis and planning. In other words, to review literature and terminology. Internet is a very rich source of published papers, journals and technical reports. Through proper searching in the internet many researches and papers can be obtained to allow for a review of the works and researches done in the field of applying GIS in transpiration and planning.

c. As an extension of the previous step, the technologies used in this area such as using internet GIS in transportation is also reviewed.

d. Then show the contribution and the practical application of GIS in transportation field. To do this work, a search for case studies is required. Again internet is a good source to find good case studies carried out in the practical life and published through journals and technical reports. So, in this step, two case studies are summarized and included in this paper.

e. Each case study is followed by a discussion includes the findings from the study.

f. This is the final step in this research. In this step, Recommendations are suggested to improve the GIS applications in transportation analysis and planning.

4. Review of Literature and Terminology

4.1 Definition of Geographic Information System (GIS)

Geographical Information System (GIS) - System of computer hardware, software, and procedures designed to support the capture, management, manipulation, analysis, modeling, and display of spatially referenced data for solving complex planning and management problems. GIS is a computer-based system used to capture, store, edit, analyze, display, and plot geographically referenced data. GIS was pioneered in the 1960s by the Canadian forestry mapping initiative and continued to develop as Canadian, U.S., and other government and university researchers sought to represent the earth's geography using a computer database, display it on a computer terminal, and plot it on paper. They also developed computer programs to quickly search and analyze this data. The typical GIS is founded on several basic concepts. First, the real-world features on the earth's surface are related to a map grid coordinate system and recorded in the computer. The computer stores the grid coordinates of these features to show where they are, and the attributes of these map features to show what they are. Second, map features can be displayed or plotted in any combination and at virtually any map scale, making computerized mapping data far more flexible to use than traditional paper maps. Third, the GIS can analyze the "spatial" (locational) relationships among map features.

The capability of GIS technology to process both spatial and attribute data offers the opportunity of using GIS in locational analysis. GIS facilitates effective decision-making by planners in planning. GIS goes beyond the limits of paper maps in manipulating and analyzing spatial data. The advantages of GIS in data documentation and processing include (Al-Ramadan & Aina 2004):

- Quick updating of information
- Automated cartography
- Integration of information by linking spatial and attribute data
- Spatial analysis
- Production of maps at different scales and
- Visualization.

4.2 Benefits of GIS

The following are some of the GIS's benefits (Al-Ramadan 2002):

- Integrating Geographic Information for display and analysis within the framework of a single consistent system;
- Allowing manipulation and display of geographic knowledge in new and exciting ways.
- Automating Geographic Information and transferring them from paper to digital format;
- Linking location and attributes of feature(s) within the framework of one system;
- Providing the ability to manipulate and analyze Geographic Information in ways that are not possible manually;
- Automation of map making, production and updating;
- Providing a unified database that can be accessed by more than one department or agency;
- Storing Geographic Information in coincident and continuous layers.

4.3 Uses and Urban Applications of GIS

Geographic information systems can be used for many purposes. They may be used to determine optimum locations for roads, railroads, airports, utilities, subdivisions, retail market outlets, and hazardous waste facilities. They help both government and industry to efficiently manage their infrastructure such as water, gas, electric, telephone, and sewer lines.

They can be used to make maps, to establish the most efficient routes for emergency vehicles and school buses, to locate fire hydrants, to plan snow removal, and to appraise real estate. Several dozen' federal agencies are presently making use of these systems in one way or another.

Business geographies is the latest trend in GIS. It is probable that at least 80% of business information is tied to geography. (Think of the costs involved for a company that chooses a poor site for their business.) Today over 98% of the Fortune 500 companies in the United States use GIS for, the following (McCormac 2004):

1. Market analysis
2. Customer analysis

3. Competitor analysis
4. Site selection
5. Studies for moving goods from warehouses to various customers

GIS supports a variety of urban applications such as (Al-Ramadan 2002):

1. Permit issuing and tracking
2. Municipal Facilities Management
3. Zoning and Subdivision Plan Review
4. Urban Land Use Planning
5. Land Records Management
6. Emergency Vehicle Routing and Dispatching
7. Inventory of Utilities
8. Inventory of vacant Land parcels
9. Urban Growth Management
10. Transportation Analysis and Planning
11. Optimum Site Selection for schools, hospitals, and commercial centers.

4.4 Levels of Use of GIS

The three levels that a geographic information system might be used are as follows:

1. **Data Management:** The GIS is used to input and store data, to retrieve that data through spatial and conditional queries, and to display the results. For the data management type of application, the GIS is merely used as an inventory system with the purpose of storing and displaying information about spatial features. These features are things like the width, number of lanes, and traffic count for a particular highway.

2. **Analysis:** The second level of GIS application is the analysis. Examples include determining the shortest path between two locations, grouping of areas of land into larger ones depending on certain criteria, and so on.

3. **Prediction.** It is the highest application level of GIS. It falls into the prediction of "What if?" category. At this level the data management and analysis capabilities of a GIS are combined into a modeling operation such as predicting the effect on traffic on a certain highway when certain land areas

are developed in a certain way, predicting the effect of a hurricane, or predicting the effect of a certain disaster on air quality.

4.5 Objectives of GIS

The primary objectives of GIS are:

- Reduce the time – and – money consuming activities of handling, recording and researching data.
- Takes row data and transform it by overlap and by various analytical calculations into new information that can help the analyst to make decisions.

4.6 Essential Elements of A GIS

There are five essential elements in developing and using a geographic information system (GIS). These are: data acquisition, preprocessing, data management, manipulation and analysis, and product generation. For any given application of a geographic information system it is important to view these elements as a continuing process. Each of these dements is briefly discussed in the sections that follow (McCormac 2004).

4.6.1 Data Acquisition

The data used in a GIS is of two types-spatial or attribute. **Spatial** data describes the geographic location of various entities such as zip code areas, county boundaries, and roads in terms of latitude and longitude or other appropriate format. An **attribute** is a property or characteristic that may be ascribed to a certain thing or feature. It may be numeric (population counts, household units, and so on) or it may pertain to character (the name of a zip code, household unit, etc.) There are various sources of acquiring data:

- Buying or getting the data from various branches of government or agencies. This data might be in form of maps or aerial photos along with much non-spatial data. Such data belongs to the public unless it is of importance to national security.
- In case of insufficient data be available from the sources, it will be necessary to collect more data from the field.

- Another source of data is called imagery data. These are aerial photos but they can include satellite images.

4.6.2 Preprocessing

Preprocessing involves manipulating data in several ways so that it is converted into a format that can be used by a GIS. Important preprocessing elements include data format conversion and identifying locations of the objects in original data in a systematic way. Converting the format of original data often involves the extraction of information from maps, photographs and printed records (such as demographic reports) and the recording of that information in a computer database. Some of the preprocessing items are:

1. Matching edges of two different coverages.
2. Eliminating unnecessary lines, polygons, or points.
3. Establishing standards for maintaining spatial data in terms of projection systems, datums, etc ..
4. Converting data into a format that can be used by the GIS software.
5. Establishing a consistent system for recording and specifying the location of objects in the data sets. When the task is completed, it is possible to determine the characteristics of any specified location in terms of the contents of any data layer in the system.

4.6.3 Data Management

Data management functions govern the creation of and access to the database itself. These functions provide consistent methods of data entry, updating, deletion, and retrieval. It is obviously important to keep the data up-to-date arid this task requires that data be constantly monitored and checked to see if it is obsolete. If it is obsolete, care must be taken to replace it with current data since wrong data will lead to wrong conclusions and hence poor business decisions.

Also included in data management are concerns with the issue of security. Procedures must be in place to provide different users with different kinds of access to the system and database. For example, database update may be permitted only after a control authority has verified that changes are both appropriate and correct.

4.6.4 Manipulation and Analysis

This part of the system contains various analytical operators, which can be used to generate sophisticated queries based on user requirements that are classified into two categories: spatial queries and aspatial queries.

Spatial Queries: These are essentially involved with querying the geographic components of a GIS, that is, the lines, polygons, and points. Some of these queries are explained below.

1. Overlaying. This is the process of overlaying one area of a GIS with another to retrieve information about their combined impact.
2. Buffering. This operation creates buffer zones for investigation around the geographic objects under study
3. Least cost/impedance path. This is used to find out the shortest distance between two points based on various criteria.

Aspatial Queries: Aspatial queries are those that involve querying attribute data concerning such items as census data, weather related data, etc. Attribute data that is related to spatial components of a GIS are queried and the resulting queries are then displayed on the spatial components, giving the user a visual representation of the query. Spatial queries are of various types such as intersection queries, union queries, and user defined queries. Given below are some examples of these types of queries.

1. Select all zip code polygons where median income of residents exceeds $50,000 and where the average annual snowfall is less than 30 inches (intersection).
2. Select all census tracts in South Carolina where the median price of a single, family home is less than $45,000 and where the percentage of the population living under the poverty level is greater than 25% (union).
3. Select all zip code polygons with average wind speeds greater than 12 knots (user defined).

4.6.5 Product Generation

The final element of a GIS is product generation where the results of various analyses are presented. This output could be a soft copy that is displayed on the computer screen or a hard copy that is printed on paper. Various types of products generated in a GIS are statistical reports, maps, graphs, and accompanying text. While statistical reports can be printed on white paper, maps and graphs can be printed with a regular printer or with a plotter where it can be many times larger in size than is customary with a regular computer printer.

4.7 Putting Data into the Computer

There are five general ways in which data is entered into computers. These are as follows:

1. **Keyboard entry:** With this method information is manually entered into the computer. Most attribute data is entered in this way.
2. **Coordinate geometry**: With coordinate geometry, usually called COGO, survey measurements are manually entered by keyboard. Then from this data the coordinates of the spatial features involved are determined by the computer.
3. **Digitizing:** This method is used to transfer the data on an existing map into the computer. The various positions are accurately measured and the data is transferred to the computer in digital form.
4. **Scanning:** Scanners use either an optical laser or some other type of electronic device to scan maps and convert their images to a raster format. Some computer processing is necessary to improve the quality of the work and to convert it to a vector format. The most Common type of scanner used for converting maps for GIS work is the drum scanner. The maps are scanned by attaching them to a rotating drum.
5. **Inputting existing digital files:** Data is prepared in digital form to be input directly into computers.

4.8 Spatial Data Models

There are two approaches to the representation of a geographic information system: the raster model and the vector model.

In a raster model, the area is subdivided into tiny cells and objects are represented in the corresponding cells. Each cell in a raster file is assigned only one value. Each of the cells represents one map unit usually chosen to be shown on the map as one screen display unit or pixel. The rows of the raster are usually established parallel to the east-west direction and the columns in the north-south direction.

In the vector model, geographic data is divided into points, lines, and polygons. Vector data is more satisfactory for representing features with discrete edges such as roads and power lines and for items such as rivers. A point is represented by a single pair of coordinates; it is used to represent too small objects to be represented by a line or a polygon such as manholes, water wells, houses, and advertising signs. A line is represented by a set of coordinates; it is used to represent too narrow objects to be displayed as an area such as roads, rivers, power lines, and so on fall into this class. A polygon is a closed loop formed by a set of coordinates and is used to show countries, lakes, zip code areas, etc.

4.9 Geographical Data

1. **Points:** Point data applies to observations that occur only at points or at least at extremely small areas in proportion to the scale of the database. Features such as telephone booths, fire hydrants, and bus stops illustrate data that occupies a single point.

2. **Line Data:** Highways, railroads, rivers, pipelines, and power lines exemplify line data. Vector systems can show this data with fine detail but a raster-based system can only depict such linear features with chains of cells.

3. **Area Data:** Continuous two-dimensional items such as lakes, agricultural areas, and parking lots are depicted by area data. Such items as highways, rivers, canals, and so on may also be included in area data depending on the level of data of a GIS.

4.10 Coordinates and Map Projections

Maps are flat but the surfaces they represent are curved. The transformation of three-dimensional space onto a two-dimensional map is called projection (McCormac 2004). Projection formulas are mathematical equations that convert the data from a geographical system (latitude and longitude) on a sphere or spheroid to a representative location on a flat surface. This process inevitably distorts at least one or more of the following properties: shape, area, distance, or direction. Since measurements of one or more of these perhaps distorted properties are often used to make decisions, anyone who uses the maps as analytical tools needs to know which types of map projections distort which properties. The various types of map projections and the properties they preserve are as follows:

1. **Conformal maps**: preserve local shape. Those maps that are used for presentation to others normally use conformal projections.
2. **Equal area or equivalent maps**: retain all areas at the same scale. These types of projections are normally used for thematic and distribution maps.
3. **True direction maps**: are those that express certain accurate directions. Navigational maps are good examples of these types of projections.

Various methods have been developed for projection curved areas on flat maps. Examples of those methods are the state plane coordinate system, the tangent plane projection, the Lambert projection, and the Universal Transverse Mercator (UTM) (McCormac 2004).

4.11 GIS in Transportation Planning

Information System (GIS) are becoming more widely used in transportation planning agencies, especially among metropolitan transportation organizations. In many developed countries, highway maintenance management is becoming a critical issue. Many more authorities are now able to use GIS for Highways and transport management, due to falling costs and GIS increasing overfriendliness. GIS offer transport planners a medium for storing and analyzing data on population densities, land uses, travel behavior, etc. The most important objectives for using GIS are map/display and data integration. Agencies must identify potential issues that can be addressed through a GIS application more efficiently and effectively, and more economically than with prevailing methods. Federal, state and local agencies are using GIS information to develop transportation policy and planning (Gupta *et al.* 2003).

The use of GIS for transportation applications is widespread. Typical applications include highway maintenance, traffic modeling, accident analysis, and route planning and environmental assessment of road schemes. A fundamental requirement for most transportation GIS is a structured road network. Additional information concerning general topography, land cover and land use is pertinent to the consideration of the impact of construction. The lack of appropriate data for GIS remains a chronic problem. GIS describes a world in terms of longitudes and latitudes and other projection systems consisting of a hierarchical structure of graphical objects. The typical GIS represent the world as a map. The major requirements and issues surrounding GIS management technology are building and maintaining a database, selecting and upgrading hardware and software, using the technology to solve problems, funding, networking, providing access, and others. Standard GIS functions include thematic mapping, statistics, charting, matrix manipulation, decision support system, modeling and algorithms and simultaneous access to several databases.

4.11.1 Role of GIS in Transportation Engineering

The application of GIS has relevance to transportation due to the essentially spatially distributed nature of transportation related data, and the need for various types of network level analysis, statistical analysis and spatial analysis and manipulation. Most transportation impacts are spatial. At GIS platform, the transport network database is generally extended by integrating many sets of its attribute and spatial data through its linear referencing system. Moreover, GIS will facilitate integration of all other socioeconomic data with transport network database for wide variety of planning functions.

The main advantage of using GIS is its ability to access and analyze spatially distributed data with respect to its actual spatial location overlaid on a base map of the area of coverage that allows analysis not possible with the other database management systems. The main benefit of using the GIS is not merely the user-friendly visual access and display, but also the spatial analysis capability and the applicability to apply standard GIS functionalities such as thematic mapping, charting, network-level analysis, simultaneous access to several layers of data and the overlayment of same, as well as the ability to interface with external programs and software for decision support, data management, and user-specific functions (Vonderohe, 1993).

The existing database does not allow the user to manipulate, access, and query the database other than in a very limited way. The user is limited to textual queries only, the selection and viewing of crossing attribute data with respect to spatial and topological relationships is not possible. Over related data, such as land use, population, and the road network characteristics of the area in the crossings vicinity, cannot be accessed in the present database. This ability of GIS, along with the final presentation of results on a digital base map, will allow the user a better perception of the problem, enable better decisions, and allow a better understanding of what is to be achieved in a broader sense. The ability to define conditional queries, perform statistical analysis, create thematic maps, and provide charting chances the crossing safety program by allowing for better understandability of the data.

Furthermore, the ability of most GIS software to provide many basic transportation models and algorithms may also be useful in specific situations. The ability to link up to external procedures and softwares also provides flexibility, as these procedures can access data within the GIS and present the results of analysis to the GIS for viewing and analysis.

The geographic information system (GIS) could be used as a tool for highway infrastructure management in a way similar to its current application in land-based information. GIS procedures provide a coordinated methodology for drawing together a wide variety of information sources under a single, visually oriented umbrella to make them available to a diverse user audience. GIS tools can be applied to aid technical and administrative specialists both in managing costly and intensively used resources and in supplying information to decision-makers.

Potential applications for GIS in transportation planning include the following:

- Executive information system.
- Pavement management system.
- Bridge management.

- Maintenance management.
- Safety management.
- Transportation system management (TSM)
- Travel demand forecasting
- Corridor preservation and right-of-way
- Construction management
- Hazardous cargo routing
- Overweight/oversize vehicles permit routing.
- Accident analysis
- Environment impact
- Land side economic impact and value-capture analysis and others.

GIS applications can be expected in pavement management, traffic engineering, planning and research, bridge maintenance and field office support, Other planning applications include evacuation planning, planning for hazardous material release incidents, development of new traffic analysis zones from census tracts, and development of new urban highway networks. 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. The interaction between the transportation system and its surrounding environment makes the GIS technology ideally suited for hazardous material, routing design, risk analysis, and decision making. GIS can also be integrated with sophisticated mathematical models and search procedures to analyze different management options and policies (Gupta *et al.* 2003).

Engineering applications are generally restricted to the project level involving a single narrow corridor. A high level of spatial accuracy is required. Most applications are a one-time effort for the area of interest, but engineering review may be required as part of planning and management review cycles (Peuquet, 1991).

4.11.2 Related database

A number of databases should be available for use in GIS-T applications including land use, demographic, environmental, utility, and hazardous materials databases. The first three involve polygon overlays generated by other agencies. The full range of attributes associated with these databases is potentially relevant for GIS-T applications. Utility systems such as sewer and water can be represented as networks using nodes and links with appropriate attributes. Hazardous materials can be represented as a "travel demand" with an origin and destination for a hazardous cargo, or as point or polygon overlays in the case of a contaminated site. In addition, the corporate management, accounting, and budgetary systems should be available for GIS-T applications.

4.11.3 GIS-T Functionality

For the purpose of identifying and classifying GIS-T applications, seven GIS functions or groups of functions are used:

1. Basic functions (editing, display, measurements)
2. Overlay.
3. Dynamic segmentation.
4. Surface modeling.
5. Raster display and analysis
6. Routing, and
7. Links to other software (e.g., transportation modeling packages).

The basic functions are used to edit, display and measure base maps. The editing function allows the user to add or delete points, lines, or polygons and change the attributes of these features. The display function generates thematic maps that show the attributes of selected features using a variety of symbols and colors. The measurement function is needed to determine the length of lines and the area of polygons. The overlay function permits two or more base maps to be displayed simultaneously. The union of two base maps displays all the features of both maps while the intersection of two base maps only displays the features that are common to both base maps.

Dynamic segmentation involves the division or segregation of network links into segments that are homogeneous for the specified set of link attributes. The segmentation is dynamic because it is created in response to the current attributes of the network. If the attributes are changed, then" dynamic segmentation” will create a new set of homogeneous segments.

Dynamic segmentation has been introduced into GIS software in order to integrate and analyze link-based transportation system attributes. For example in pavement management, the highway base map may be initially “dynamically segmented” by bituminous versus concrete pavement type so that each network segment only contains bituminous pavement or only concrete pavement. Specification of both pavement type and number of lanes as attributes for dynamic segmentation would result in network segments with the same number of lanes for each pavement type.

The surface modeling function creates a three-dimensional model of land forms or other surface features. The digital topographic map created by the surface modeling function is essential for highway design. The actual highway design may be done with separate design software that imports the topographic map from the GIS. The resulting highway alignment is then exported to the GIS for further analysis.

The raster display function permits photographs and other images to be incorporated in a GIS. Overlays of aerial photographs with highway base maps can be used to update the base maps by adding new links, new features such as bridges or intersections, and correcting errors in alignment. Overlays with zonal (polygon) base maps can be used to code land use and other attributes.

Routing capabilities based on minimum time paths have been available in travel demand software for many years. Integration of routing in GIS software directly reduces the need to create links to other models and software. Links to other models and software, such as transportation planning demand models and highway design software, however, will still be necessary if the full power of GIS-T is to be realized.

The functionality of existing GIS-T software may constrain choice of the spatial database and the transportation modes. The available spatial databases will be least initially constraining the selection of the spatial and temporal dimensions of the possible applications. The availability of related databases will also initially impose similar constraints. In projecting future GIS-T applications, these constraints will be relaxed.

4.11.4 GIS Applications in Transportation System Engineering

Transportation is inherently geographic and therefore, GIS possesses a technology with considerable potential for achieving dramatic gains in efficiency and productivity for multitude of traditional transportation applications, as well as creating the opportunity to develop new applications. The applications of GIS to transportation can be viewed as involving either (i) Data retrieval; (ii) Data integrator; or (iii) Data analysis.

Pavement Management

Pavement Management System (PMS) contains three primary components: data collection, analysis and updating. The components under data collection include:

Inventory: Physical pavement feature including the numbers of lanes, length, width, surface type, functional classification and shoulder information.

History: Project data and type of construction, reconstruction, rehabilitation and preventive maintenance.

Condition Survey: roughness on ride, pavement surface friction, rutting and distress

Traffic: volume, vehicle type and load data; and

The components under analysis include:

Condition Analysis: ride, distress, rutting and surface friction

Performance Analysis: pavement performance analysis and an estimate of remaining service life

Investment Analysis: an estimate of network and project level investment strategies. These include single and multiyear period analysis and should consider life cycle cost evaluation.

Engineering Analysis: evaluation of design construction, rehabilitation, material, mix design and maintenance.

GIS is a logical approach for managing this program, whereby analysis of pavement section descriptions and pavement deficiencies collected in pavement condition surveys could be maintained by location. Also the distribution of maintenance and resurfacing funds may be made on the basis of lane kilometers in a geographic area and corresponding pavement condition ratings. PMS based on GIS will thus make more equitable distribution of funds and a more visual medium for making such policy decisions.

Traffic Engineering

Congestion management programs can be most suitably developed in a GIS environment. GIS based congestion management systems can start with the highway base maps and attribute databases used for long range transportation planning in urban areas. These regional base maps will provide the framework for identifying and monitoring congestion from a regional perspective. Additional more detailed base maps and databases can be developed to manage congestion in real time in critical corridors.

Safety Management

The analysis of accident data coupled with roadway features and characteristics, traffic volumes, bridge inventory and other data and the geographical presentation of this information in GIS environments will be very useful to develop safety management system. Inventory files such as traffic signals, narrow bridges and railroad crossings could be analyzed more efficiently using GIS.

Bridge Maintenance

A major benefits derived from GIS use will be in obtaining bridge information through general query capability. Example includes bridge condition surveys, sufficiency ratings, functionally deficient bridges, posted capacity distribution, clearness etc. Through relational database, bridge maintenance engineers could access important information like average daily traffic, as well as system and functional classification from planning and research maps.

New and Emerging Applications

GIS is an ideal environment for routing analysis of hazardous materials because this requires overly of many highway network attributes as well as other databases (e.g. demographic, topographic, weather etc.) on individual road segments in order to properly characterize accidents and consequence to population and environment. Other important application of GIS based system is in managing unexpected emergency evacuation even though it was not initially planned as distant management system. The road network at GIS platform will provide a framework for the development of disaster management system of any kind. The coordination among various management systems in a state can be easily planned and developed through the applications of geographic information system. These subsystems will automatically be valuable resource for many other state level systems.

4.12 Internet GIS and its Applications in Transportation

Two of the technologies of the 90s, the Internet and Geographic Information Systems (GIS) have changed the ways transportation professionals access, share, disseminate and analyze data and information. The Internet has greatly improved the accessibility and transmission of all types of information including transportation. Transportation data providers, including government agencies and private organizations, are discovering the convenience of publishing and disseminating transportation information on the World Wide Web and many have set up their own Web pages (Ren Peng 1998).

The Internet provides transportation professionals easy access to information and data from different sources. They can request and download information and data almost instantly from the Web over the Internet. It is much more efficient than transmitting data through disks. This helps transportation professionals to make more informed decisions.

Geographic Information Systems is being used to integrate, analyze and display spatial data. Because of the spatial nature of most transportation data, transportation professionals found GIS to be a powerful tool to construct and analyze transportation networks, to conduct impact assessment of transportation facilities, and to integrate transportation and land use planning. But GIS software is mostly proprietary. The use of GIS in transportation requires expensive GIS software and extensive user training. Therefore the use of GIS in transportation is somewhat limited to a small number of transportation professionals who have the resources and expertise to use it.

Use of the Internet to access and transmit data (including GIS data) assumes that the user will use the data in their local machine with stand-alone GIS software installed. This is useful in the sense that it can facilitate users to obtain data more efficiently. However, the usefulness of the Internet in this manner is very limited. GIS users have to have the traditional GIS software to view and analyze the data. What if someone does not have GIS software installed in their local machine like the majority of us do? What if a user only needs to view the transportation data and road maps on the Internet? How can we publish spatial data on the Internet and allow the user to perform some spatial analysis without owning their personal GIS software?

The emerging technology – Internet GIS combines Internet and GIS that offers transportation professionals new ways to access, share and disseminate transportation data and information. Internet GIS is a new technology that is used to handle spatial data on the Internet. It is a network-centric GIS tool that uses the Internet as a major means to access and transmit data and analysis tools to enhance the visualization and integration of spatial data. It has new features that allow transportation agencies to publish spatial data on the network for public access, and allow transportation professionals to more easily share data and to conduct transportation analysis across a network as well as at an individual site.

4.12.1 Features of Internet GIS

Internet GIS has features that have promising transportation applications through its ubiquitous accessibility over the Internet. Users do not have to buy expensive GIS software but can access GIS data and analysis functions over the Internet. Thus, Internet GIS is also called "GIS to the masses". This makes it easier for transportation agencies to disseminate transportation information to the public. The user-friendly interface of the Internet GIS can also facilitate data sharing within and between transportation agencies.

The second feature of Internet GIS is the interactivity between the users and the spatial data. Interactive GIS offers interactive maps rather than static map images on the Web. Users can work with the maps interactively by performing conventional GIS functions such as zoom, pan, identify and queries. The maps are alive on the Internet.

The third feature of Internet GIS is that it can incorporate up-to-date, real-time information. This is especially important for the applications in intelligent transportation systems. Several applications have been developed that display real time traffic information. More applications can be developed in real time travel information systems, transit information and trip planning by linking Internet GIS with automatic vehicle locators and automatic passenger counters.

4.12.2 Kinds of Internet GIS

The building block of the World Wide Web, HyperText Markup Language (HTML) does not directly support spatial data in the form of maps. Therefore, Internet GIS needs an "interpreter" on the Web to use GIS data that cannot be recognized by the HTML itself. This "interpreter" is the core component of Internet GIS. It is used to interpret user input from the Web page to a language that the GIS software can understand. It can be located at the server side as well as client computer (user) side. If the "interpreter" is located at the server side, it is called server–side Internet GIS; whereas if is located at the client computer, it is called client-side

Internet GIS. Server-side Internet GIS relies on the host computer to perform all GIS analysis, while client-side Internet GIS perform GIS analysis and processing on the Web browser on the user's local machine (Ren Peng 1998).

Server-side Internet GIS depends on the server to perform analysis and generate output. The user at a Web browser client initiates the request that is sent across the Internet to the server. The server processes the request and sends ba ck the result to the client. The most frequently used server-side application is to use Common Gateway Interfaces (CGI) script to link the HTML with GIS server. The CGI script acts as the "interpreter" to connect user input and GIS server. Figure 1 shows the working process of server-side Internet GIS.

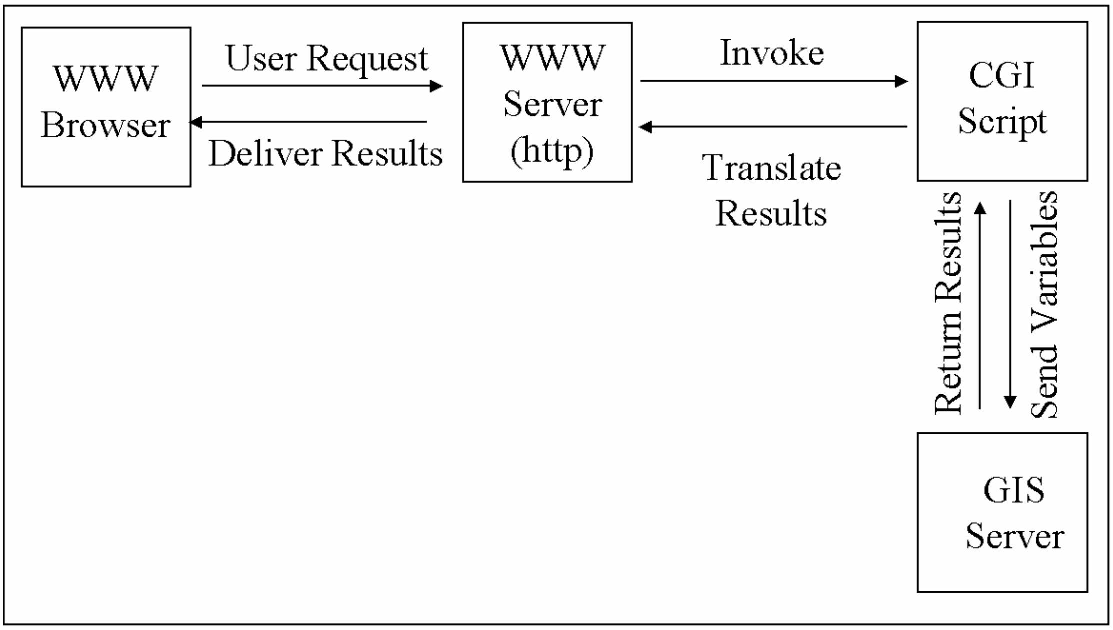

Figure1: Work process of CGI-based Internet GIS (*source: ref. 8*)

The advantage of the server-side Internet GIS is that it can handle large databases at the server and answers specific questions for the public. But it offers little flexibility and interactivity to the end user. The user cannot directly work with the data as one does with the stand-alone GIS software. The limitations of the normal data transmission protocol prohibit the development of more advanced analysis tools. It can merely be used for static spatial query and display.

Client-side Internet GIS allows GIS analysis and data processing to be done on the Web browser in the user's local machine. GIS data and analysis tools initially reside in a server. Users usually request data and processing tools from t he server, which sends the data and analysis modules to the client for local processing. Client-side applications include three major technical approaches: GIS plug-ins and helper programs, ActiveX Controls, and GIS Java applets. Figure 2 shows the working process of client-side Internet GIS.

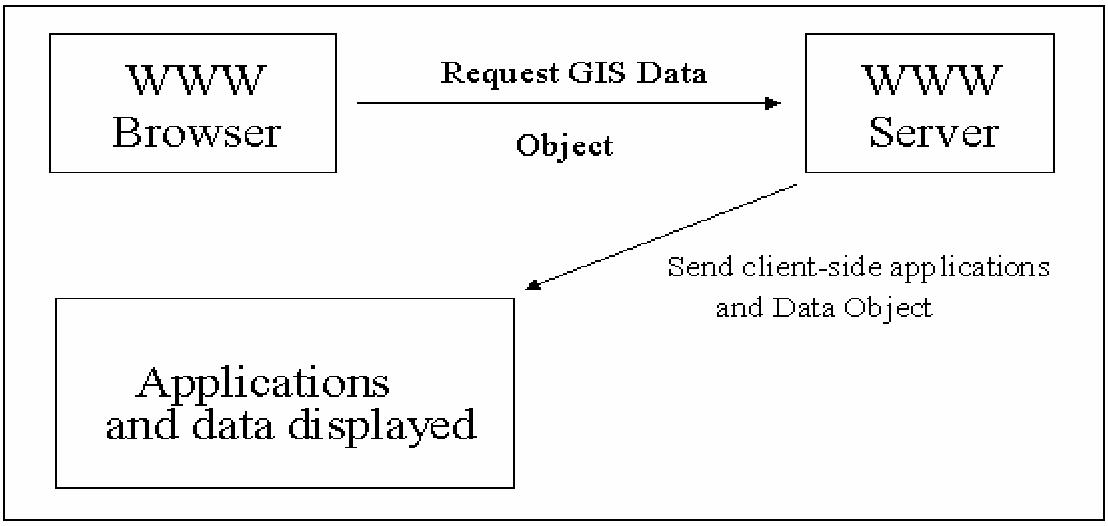

Figure 2: Work Process of Client –Side Internet GIS (*source: ref.8*)

The client-side Internet GIS offers more flexibility and interactivity between the user and the maps than the server-side applications. GIS plug-ins, helper programs and ActiveX controls extend the capability of HTTP to directly handle GIS data. The end users can view GIS data and perform simple analysis on the Web just like they do on local GIS software. But client-side Internet GIS has difficulty to handle large database.

4.12.3 Internet GIS applications in Transportation

Internet GIS provides a perfect tool to access, disseminate and visualize transportation data. Any information that can be displayed on a map such as highway and transit traffic levels, construction conditions, weather information and so forth can be transferred using Internet GIS. It also offers the potential for data sharing and transportation analysis over the Internet.

4.12.4 Interactive Road Maps

One of the major characteristics of Internet GIS is the interactions between the user and the spatial data. Users can perform GIS functions such as zoom, pan, query, and identify. This is especially useful for displaying road maps on the Internet. In addition to paper maps, State DOTs can also publish interactive road maps on the Internet. Users can zoom into (or out of) a specific area, inquire a specific address and identify a particular road links. This electronic map on the Internet is more convenient to use than the traditional paper maps. The distribution of Internet maps is also much broader than the paper maps generated by state DOTs. Anyone with a web browser can get immediate access to a road map of any portion of a state they are interested in.

Interactive road maps provide both search and browse functions. Users can search for a specific road and/or address, which results in a map that is centered around the search address. Once the user has the map, the user can zoom in or out, and pan around to browse the neighboring areas.

MapQuest (http://www.mapquest.com/) provides a good example of interactive mapping services available on the Internet. With MapQuest, the user can search for any address in the United States by imputing the street address on the Web page. MapQuest will then present a map window as shown in Figure 3. The user can further zoom in different scale such as a street level, city level or state level. The contents of the map changes according to the map scale requested. Similar services can also found in Yahoo Maps Web site (http://www.proximus.com/yahoo/).

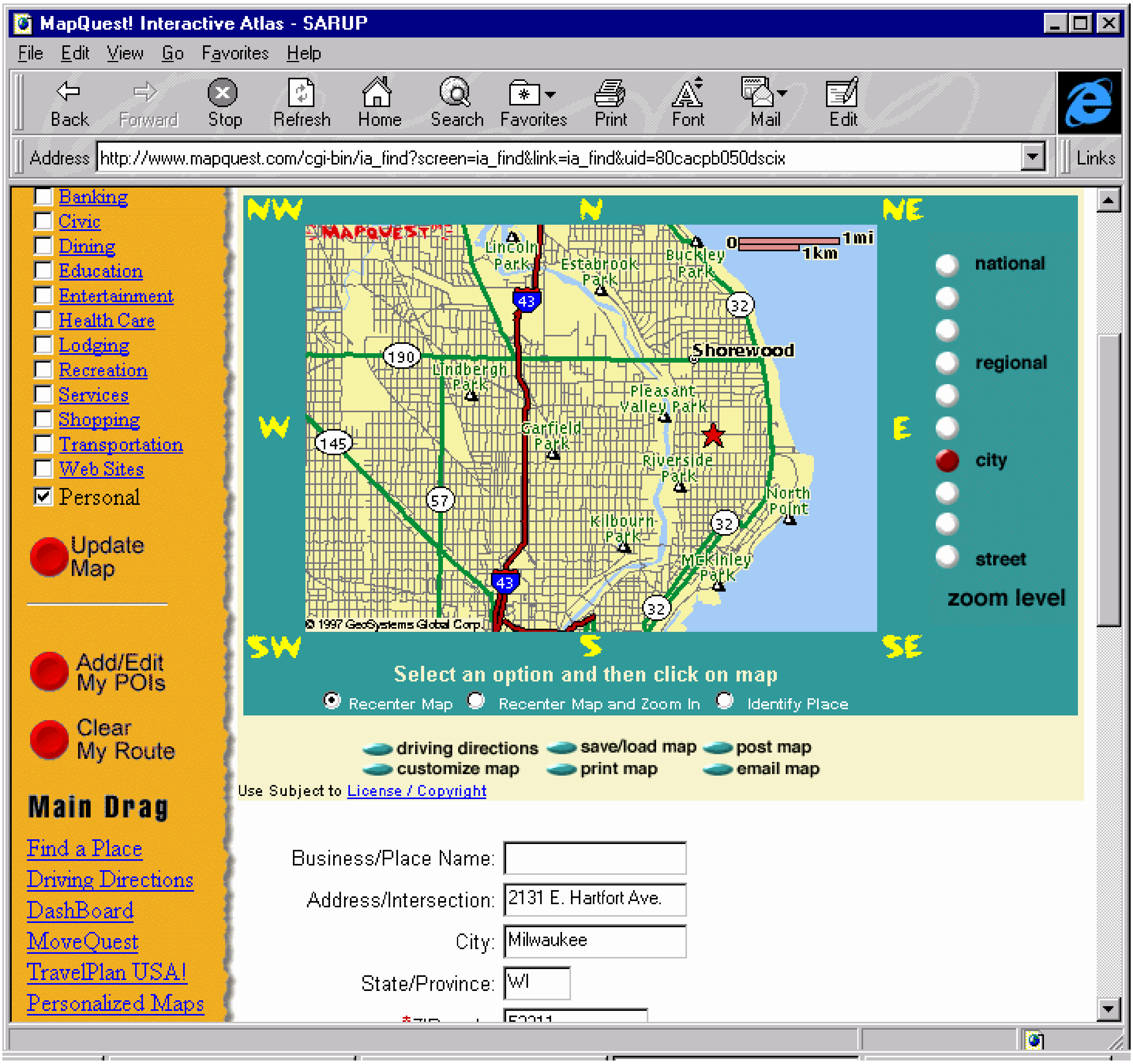

Figure 3: Interactive Road Map Presented by MapQuest, (*source: ref.8*)

4.12.5 Real-time Information on Road Conditions and Road Construction

It is also useful to provide interactive maps on the Internet so that people can find their way around. It is more valuable to provide real time information on road conditions such as road construction and weather-related road conditions. This will reduce the burden of the 1-800 phone road services. With Internet GIS, the road conditions can be easily updated and maintained. A weather-related road condition can be linked with weather information and changed in real time.

The Bureau of Automation Services at Wisconsin Department of Transportation is implementing an Internet GIS site to disseminate road closure information on the Internet using a piece of Internet GIS software: MapObject Internet Server produced by Environmental Systems Research Institute, Inc. The road closure information can be updated by authorized transportation agencies and is instantly available on the Internet.

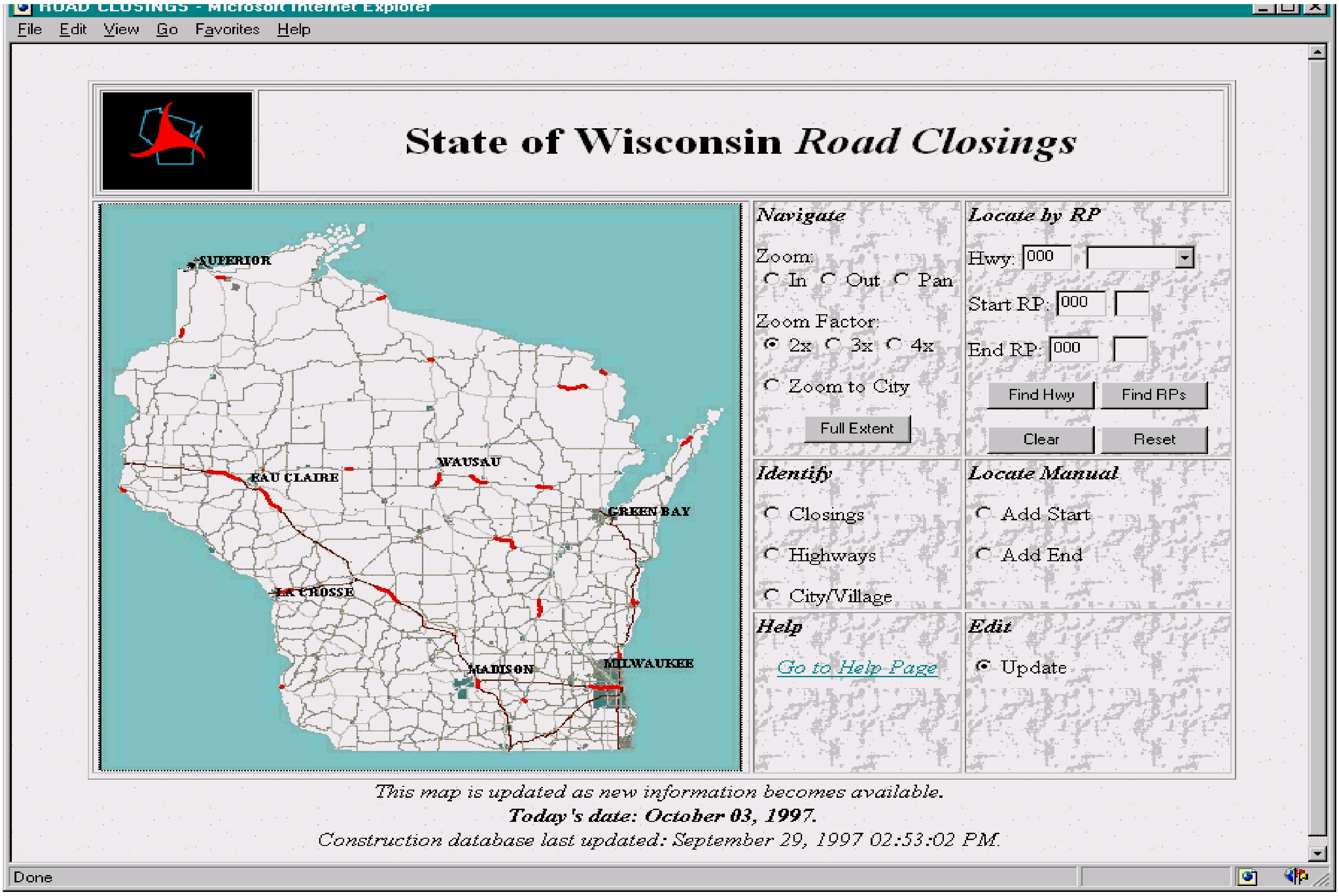

Figure 4: Snapshot of road closure information on the Internet in Wisconsin DOT (*source: ref.8*)

4.12.6 Real-time Travel Information Systems

Interactive Internet GIS is a perfect presentation tool of real time travel information once it is linked with real-time traffic information. Several state DOTs have created real-time traffic maps on the Internet using either server-side or client-side Internet GIS technology. For example, under the ITS model deployment initiative, Smart Trek at Seattle, Washington created a Traffic View (http://trafficview.seattle.sidewalk 1.com/) to present real-time traffic information on the Web. Users can view the traffic flows on the entire freeway system in the city. They can also zoom into a smaller area for a more detailed view. Users can quickly find the travel speed along a specific link on a freeway. The road link is also connected with real-time video snapshot so that the user can see the traffic flow.

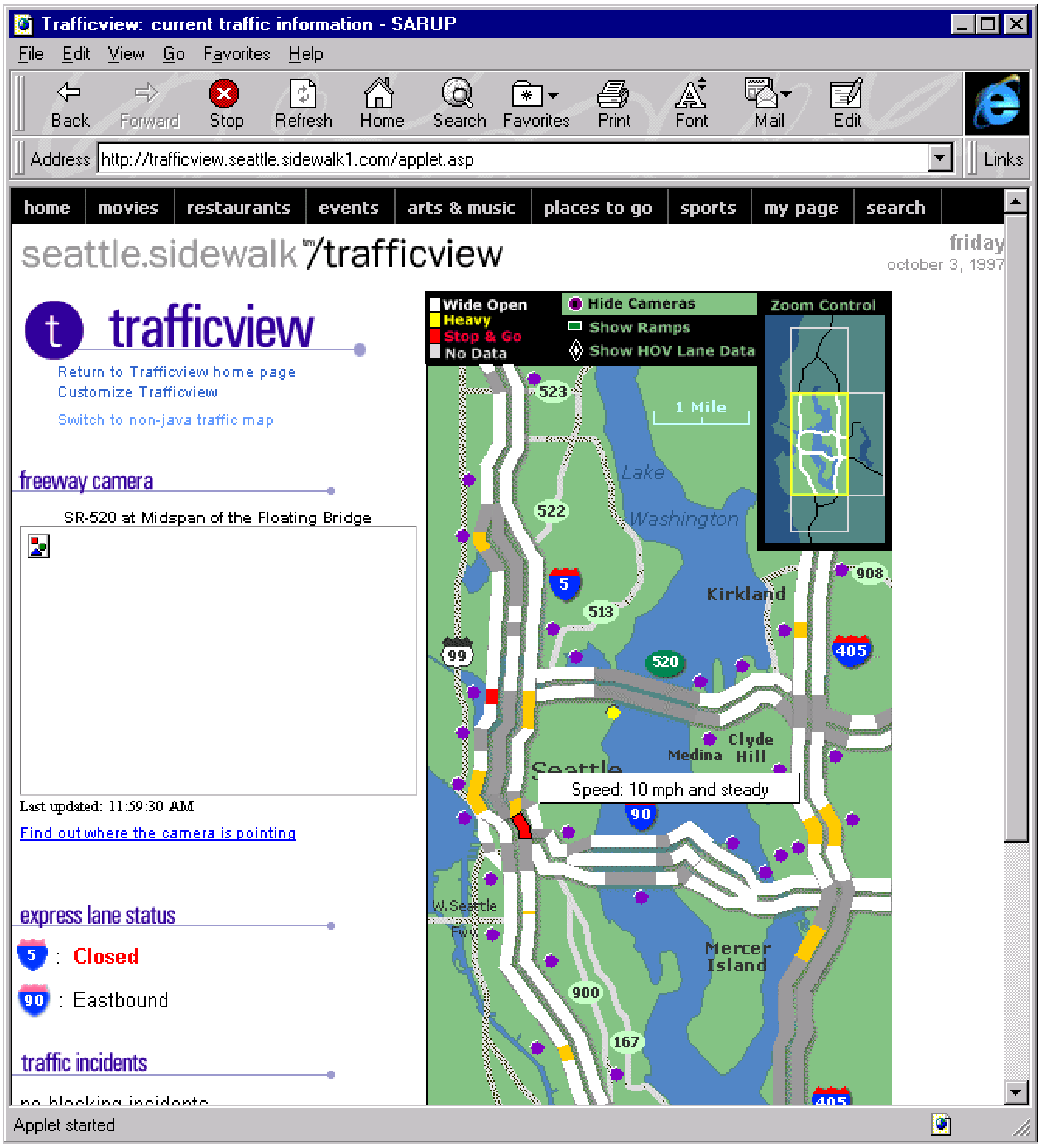

Figure 5: Snapshot of Real-time Traffic information in Seattle, (*source: ref.8*)

4.12.7 Data Sharing

Everyone realize the importance of sharing information within and across transportation agencies. But sharing data and information is difficult even within agencies, and sharing information across agencies is virtually unknown. This is partly because there is no easy way to share spatial data, partly because different data may not even be compatible. One has to call around to find out who has what data, make a request and wait for days or even weeks for the data diskettes to arrive.

That may soon change as Internet GIS enables agencies publish their data on the Web. Internet GIS offers an ideal tool for governmental agencies to share data within and across agencies. For example, a highway department can publish the ir real-time traffic information on the Web, and this information can be readily used by transit agencies for transit dispatch adjustment. Land use planning agencies can publish their land use and zoning maps on the Internet, and environmental reservation agencies can also publish their maps of environmental sensitive areas on a Web page. This information can be used by transportation planners in the development of transportation plans, and vice versa. This open data sharing system will greatly reduce the barriers within transportation departments and across other agencies.

Internet GIS offers transportation professionals at different places to be better informed by simply looking at a Web page. For example, the following map on the Internet shows the availability and accessibility of transit service to a neighborhood in Milwaukee. Transit agencies and social service agencies can share this information.

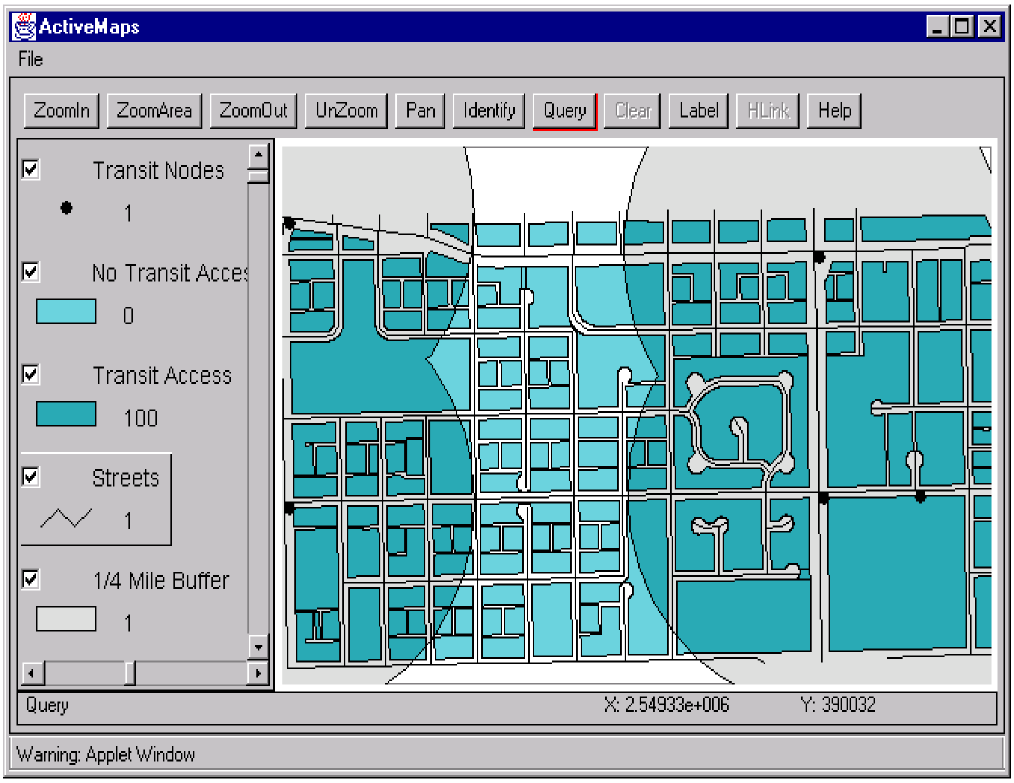

Figure 6: Snapshot of Accessibility to Transit service at Milwaukee Midtown area, (*source: ref.8*)

2.12.8 Public Involvement of Transportation Planning

The interactive Internet GIS offers an excellent channel for public involvement in the transportation planning process. Transportation planning agencies can publish information on planned road expansions or new transit routes on the Internet. The public can interact with the road plan and offer their input directly from the Web. Rather than going to town-hall meeting, the public can directly access the information right from their home. Hopefully, this would give the public more input in the transportation planning process.

4.12.9 Implications

Any new technology usually has unintended consequences. Internet GIS provides a way for transportation agencies to share information with other agencies and the general public in ways they have never done before. This can raise many questions within those organizations in how they deal with others and to what extent are they willing to share information that was not so readily available in the past.

Transportation agencies may be forced to think about how they interact with others and the how they control information. This may make some within transportation agencies uncomfortable because it can disrupt existing relationships and the internal control of the organization. To the extent that ‘knowledge is power’, procedures to make information available to more people may be seen as a threat to power. The transition from an organization with tight controls on the release of data to one that has open access will be difficult and involve issues far beyond the technology (Ren Peng 1998).

In the long run the transition to Internet GIS and wide access to information will likely be positive. There are many significant immediate benefits to users, which can help improve transportation services. Greater scrutiny of information by others will mean that more effort will be made to provide valid and useful data. This will improve procedures and techniques over time. Agencies will need to think about this to assure a good transition to more open access to their information.

5. Case Studies

5.1 Case Study 1: Transportation System Management for Madurai City Using GIS

To study the effect of the Transportation System Management (TSM) measures, one needs to have a clear view of the flow patterns, locations, as well as existing road network and must be able to analyze the attributes related to them. Geographic Information System (GIS) helps to do these things effectively and efficiently. The Madurai Local Planning Area (LPA) has been selected for study of TSM measures. GIS is used to the study the effect of TSM measures. Madurai LPA road network and location of important places are added as layers. Attributes are added in the form of databases from which one can retrieve data by making queries. Conversion of one-way streets, diversion of traffic, odd-even vehicle restrictions, parking management, effect of ring roads, and overall improvement in the network are studied with the help of GIS .ArcView and Avenue are used for the development of this package.

5.1.1 Introduction

It has been the experience of many traffic planners that most transportation plans rarely progress beyond the drawing board due to lack of financial resources and other related constraints. The only recourse open to the traffic manager therefore is the option of optimizing existing facilities to provide improved accessibility and mobility at a satisfactory level of safety and comfort to most of the road users. This can be achieved by studying and evaluating the problem in the light of sound and tested traffic management techniques, which are essentially low cost, easily implement and flexible. These are short-term solutions, primarily intended to reduce the intensity of inconvenience caused by congestion. They may not offer a permanent solution, yet they lend themselves to some time earning relief up to a point where the administration may launch the long term and short term planning. Objective of short-term solutions should be within the perspective and is compatible with the goals setout in the long-term measures.

Though the identification of the problems and the correct diagnosis may automatically suggest the usefulness of a particular management technique, the application of the single technique, in isolation, is rarely sufficient in bringing about a significant improvement in the Level of Service (LOS) and transportation mobility of an area. More often than not, the problems shifted to the adjacent locality or an entirely new problem is spawned as a consequence of the very technique used as a solution, if applied in isolation. It is therefore, essential to seek solutions in a combination of techniques, even in a relatively local situation, for effective management. A solution must be observed as a part of the total scenario and the systems approach used to prepare a Transportation System Management (TSM) Plan for the entire network.

5.1.2 The Study Area

The Madurai Local Planning Area (LPA) has been taken for the study. Madurai is the second largest City in Tamilnadu State, having a very old history of about two thousand six hundred years and is often referred to as the *Athens of East*. It has three National Highways namely NH-7, NH-45B, NH-49 and state highways passing through it. The study area is limited to Madurai Local Planning Area (LPA). The land use details of the urban and rural settlement of the Local Planning Area are given in Table 1 below.

Sl.No	Land use zone	Area (ha)	Percentage of developed area
1	Residential	1817.60	74.89
2	Commercial	41.42	1.70
3	Industrial	76.76	3.16
4	Educational	99.50	4.10
5	Public and semi-public	181.79	7.48
6	Transportation	212.38	8.74

Table 1: Land Use Details of Madurai LPA, (*source: ref.9*)

The heavy settlement has made Madurai as highly congested. The area for transportation infrastructure is less than ten percent of the developed area leading to transportation problems in the LPA. Different transportation system management measures that can be applied feasibly during the present and the future conditions of Madurai LPA road network are discussed below. For that purpose forecasting of future traffic and capacity calculation for different road links are made.

5.1.3 GIS Based TSM

5.1.3.1 Forecasting the Traffic

The traffic volume for the year 2002 and future year 2007 are forecasted with respect to the 1997 traffic volume taken from the CTTS Report (Santhakumar *et al.* 2003), vehicle growth rate and the sample survey conducted at different locations. However, the capacity restraints are not taken into account. The traffic volume count made at different selected locations the percentage share of each type of vehicle is computed. The PCU values are assigned and the total PCU share of each vehicle is obtained on each link. Figure 7 shows the traffic flow in the CBD.

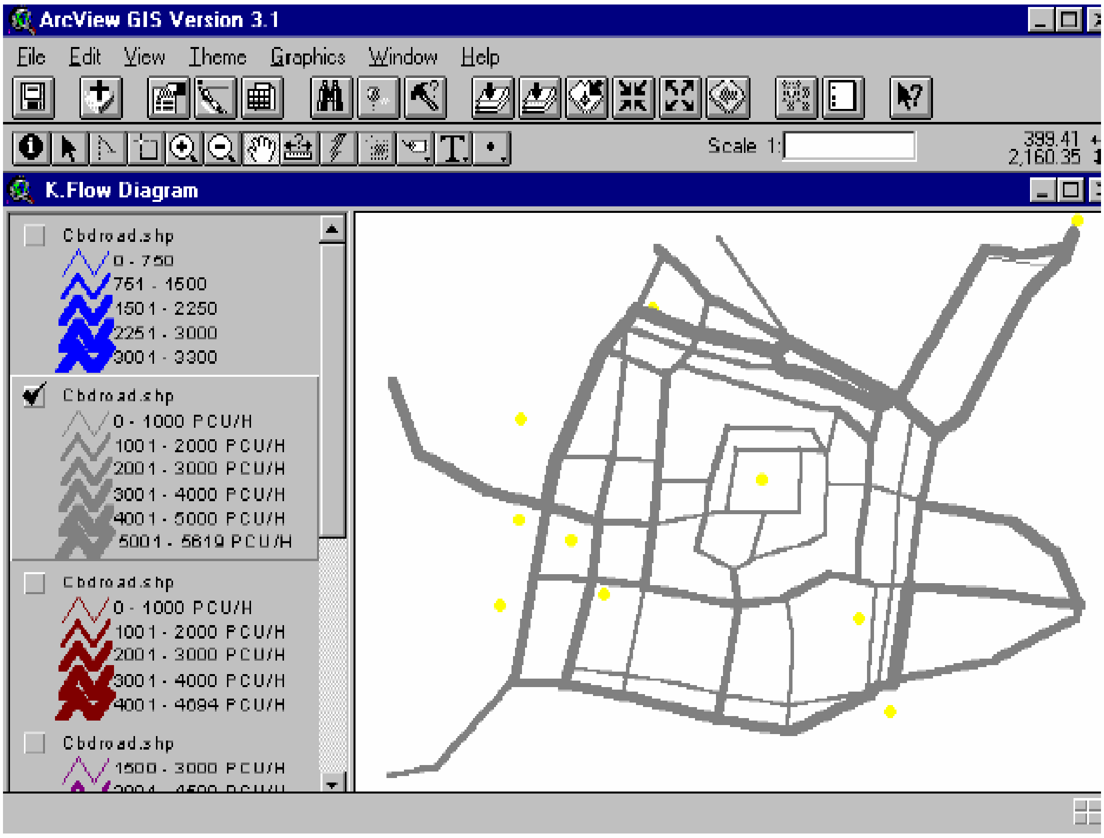

Figure 7: Peak Hour Traffic Flow in CBD, *(source: ref.9*)

5.1.3.2 Conversion of One-way Streets

South Veli and East Veli Streets of the CBD are identified as highly congested. They can be made as one-way streets, with the help of the parallel streets. Analysis was conducted on the peak hour volume count made during morning and evening at South Veli, East Veli,and their parallel streets South Marret and East Marret. From that the maximum peak hour composition in each direction is found out and assigned to the roads by comparing their capacities. As per the rules of Madurai Corporation buses are not permitted to operate on the inner roads within the Veli streets. It is taken into consideration and the movement of buses alone may be allowed through the Veli Street even after the conversion of those roads as one-way streets. The streets before and after the introduction of one-way streets are shown in Figures 8 and 9 respectively.

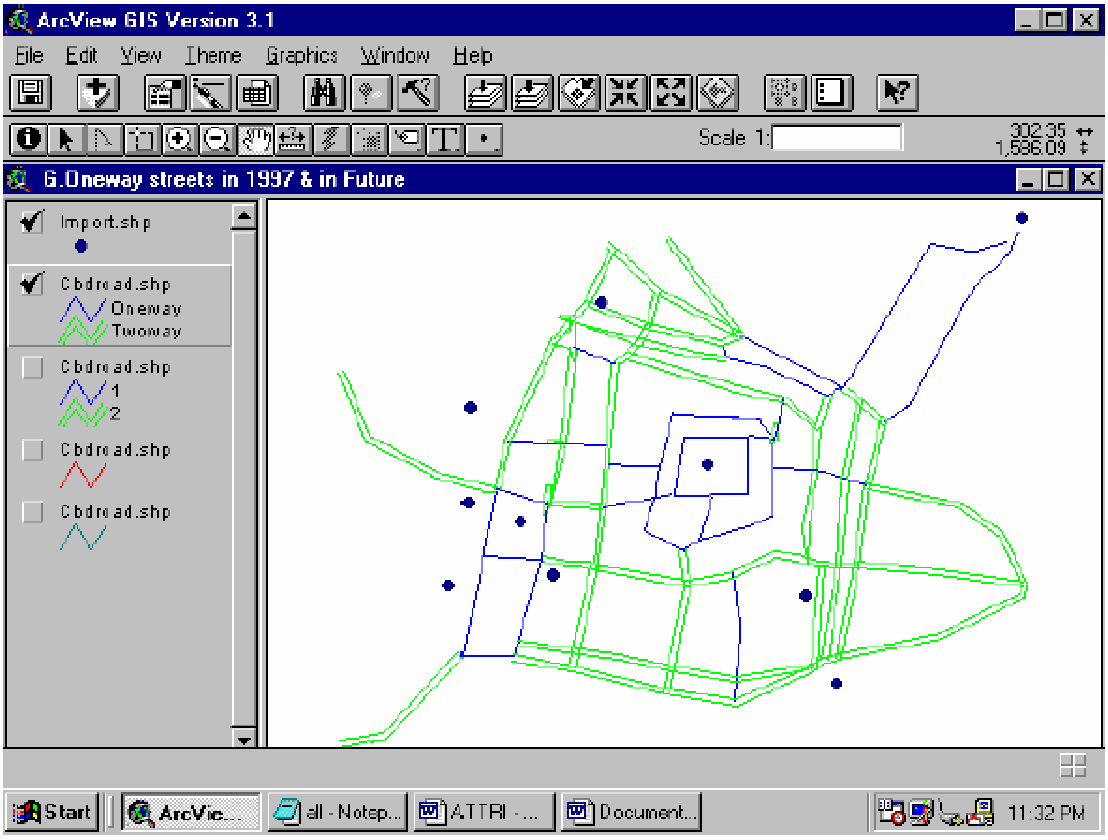

Figure 8: Before Introduction One-way Streets in Madurai CBD, (*source: ref.9*)

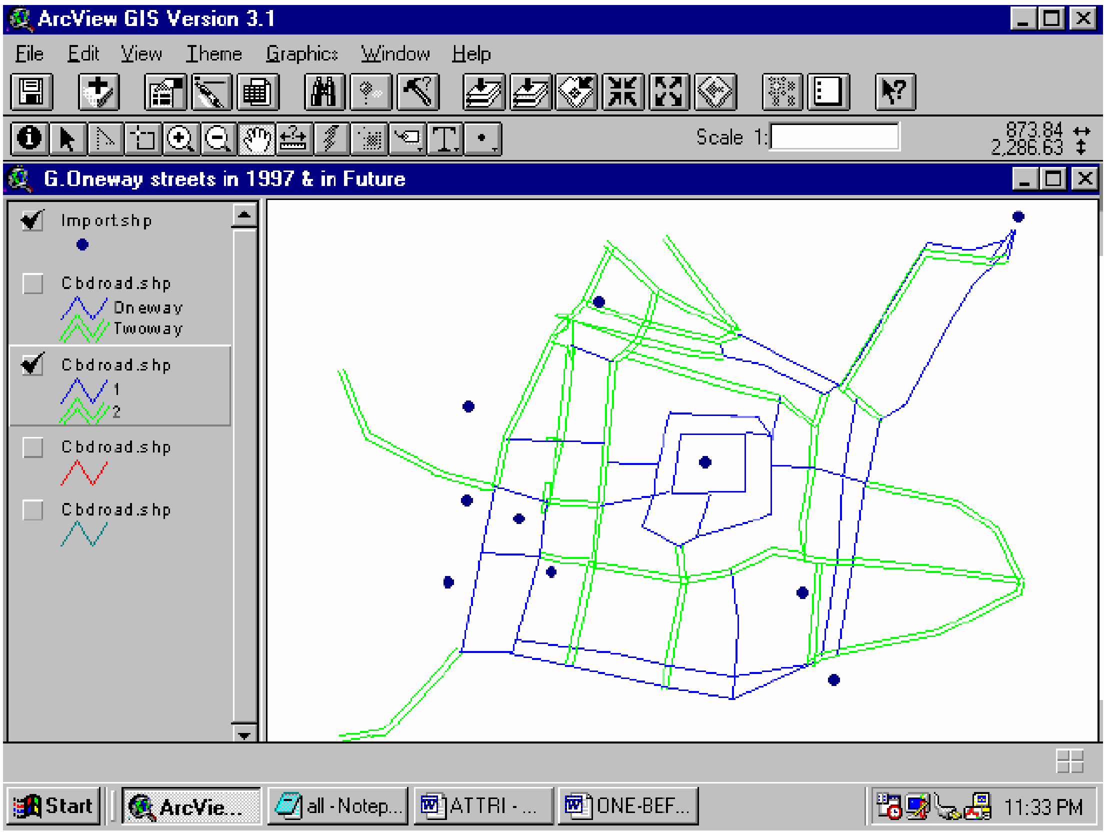

Figure 9: After Introduction One-way Streets in Madurai CBD, (*source: ref.9*)

After the conversion of the existing two-way streets to one-way streets the reduction in the V/C Ratio and improvement in the whole network was studied. By running the Avenue script and selecting the required LOS from the list, the links falling under that category will be selected. This process (LOS = A) is shown in Figure 10.

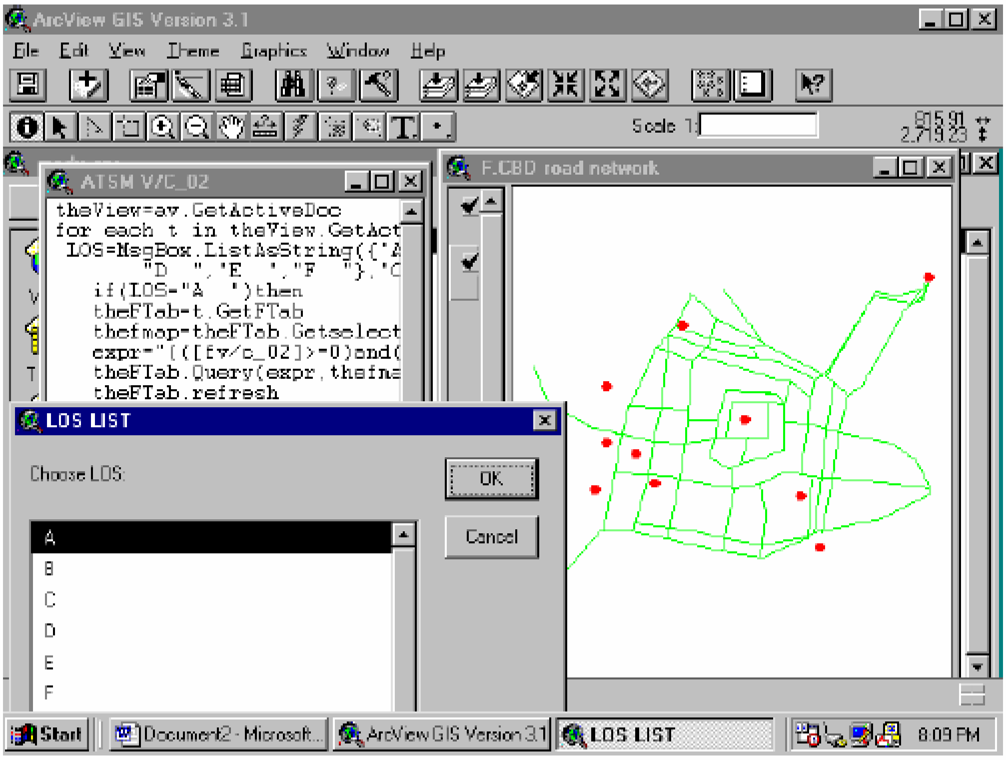

Figure 10: Level of Service A, (*source: ref.9*)

5.1.3.3 Other TSM Measures

Other TSM measures are studied: Diversion of Traffic and Parking Management. The effect on overall V/C ratio for the entire city road network due to One-way streets, Parking Management System and Diversion of Traffic is presented in Table 2. Analysis shows that the overall V/C ratio is less than 0.81 for the present condition. But for the year 2007 the overall V/C ratio is greater than 1.15. Hence the long-term TSM measures such as widening of roads and construction new roads may be implemented to reduce the congestion in the future.

TSM Measures	Effect for the year 2002		Effect for the year 2007	
	Before	After	Before	After
One-way Street	0.94	0.74	1.89	1.15
Parking Restriction	1.02	0.81	2.14	1.45
Diversion of Traffic	1.24	0.80	2.74	1.79

Table2: Effect on V/C Ratio before and after Application of TSM Measures, (*source: ref. 9*)

5.1.3.4 Overall Improvement

The overall improvement made in the LOS after the applications of all the measures is studied, by giving weightage to the length of the links. The LOS offered on each link before and after the application of TSM measures are represented in the form of color-coded maps. These color coded maps help the planner in choosing the roads has to be considered for the upgrading in the present and for the future traffic conditions. The effect on LOS for the year2002 before and after application of all TSM measures is shown in Figures 11 and 12 respectively.

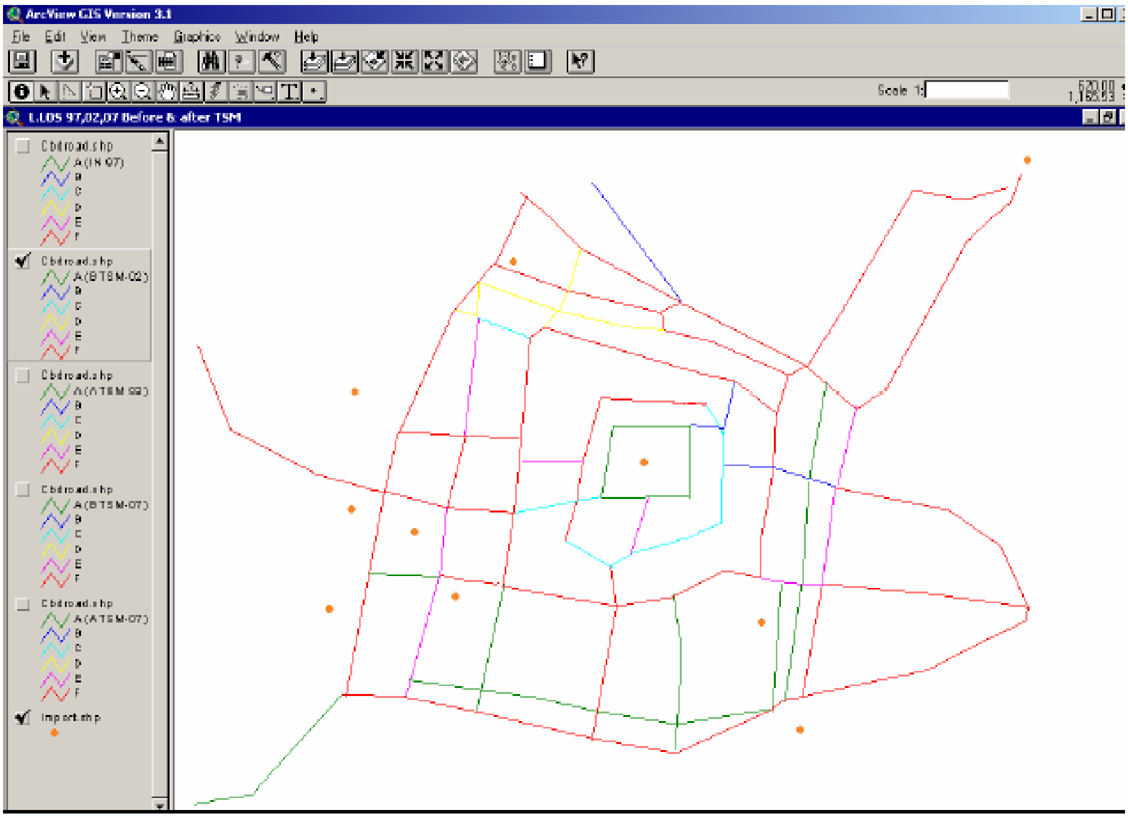

Figure 11: Level of Service in CBD before Application of TSM Measures, (*source: ref.9*)

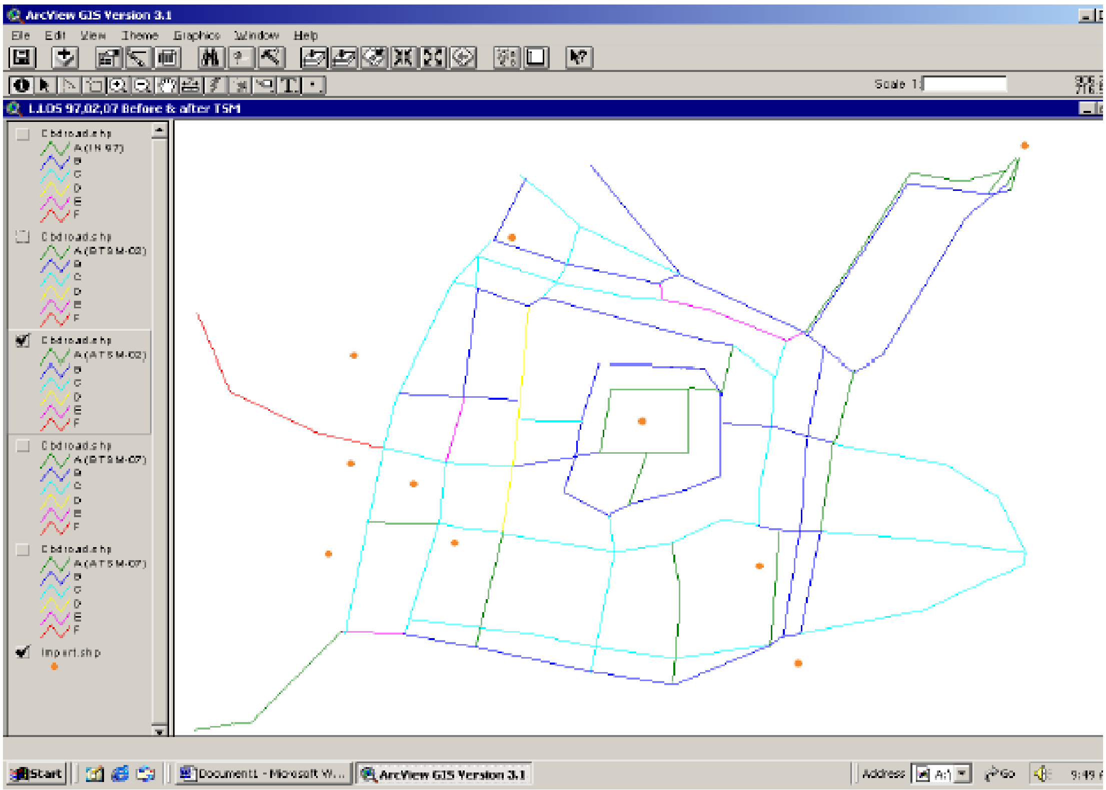

Figure 12: Level of Service in CBD after Application of TSM Measures (2002), (*source:* *ref.9*)

5.1.4 Discussion

TSM studies for the Madurai Local Planning Area are effectively carried out using ArcView GIS 3.1. The use of colored and coded maps help the planner to choose the roads that has to be considered for the upgrading in the present and for the future traffic conditions. Also, the effect applying each TSM measure is shown clearly by the aid of ArcView GIS which helps to obtain more clear and accurate results. On the other hand, the use of ArcView GIS reduces the amount of paper maps and data that could be used in absence of ArcView GIS.

5.2 Case Study 2: Application of GIS in Transportation Planning: The Case of Riyadh, the Kingdom of Saudi Arabia

This case study is an attempt to review the role of GIS in transportation planning in Saudi Arabia through introducing a symbolic case study of Riyadh city, the capital of Saudi Arabia.

5.2.1 Introduction

Riyadh’s city municipality is the prime planning organization. It consists of fifteen sub-municipalities, with a population of approximately four million and covers an area of nearly four thousand square kilometers (Alterkawi 2001). Transportation planning projects can be managed by either the ministry of transportation, Arriyadh’s Development Authority (ADA) or by Arriyadh’s Municipality. A travel demand planning process should be utilized in addressing the region's transportation needs to support planners in decision-making. A combined travel demand analysis and emission estimation process ensures conformity of transportation plans with air-quality standards (Alterkawi 2001). Riyadh’s Municipality has adopted various GIS engines (software) for different transportation planning applications such as travel demand planning, network maintenance and updating, dynamic segmentation and networking, buffer analysis.

5.2.2 Travel Demand Planning

As in any transportation planning study, transportation planning in Riyadh employs travel demand modeling process based on production and attraction of travel between activity areas. Trip Distribution Models are used to examine the regional travel characteristics. Since activities are based on a network of roads and projects, GIS is used in illustrating and manipulating the analysis of results. GIS is used in modeling activities for long and short range planning network maintenance and updating.

5.2.3 Network Maintenance and Updating

Riyadh’s Municipality has adopted various GIS engines (software) regardless of vendors since they feature a so-called open system, GIS via localized database (Alterkawi 2001). Due to its compatibility, this certainly enabled various planning departments to use it. In GIS, a links attribute table, which contains links, characterized is attached to the network map. Using the GIS capability of displaying the network attribute table along with a graphic display, link attributes can be corrected and updated. In addition, results of travel demand analysis are attached and stored in the network attribute tables, such as a link's modeled volume, speed, and impedance. As needed, colored maps of the roadway network displaying the different kinds of information redeveloped illustrating spatial relationships, temporal changes in travel needs, or locating facilities based on class, number of lanes, congestion and speed.

5.2.4 Dynamic Segmentation and Networking

In order to determine the spatial attributes of project proposed for inclusion in the short range planning (SRP), GIS is used to develop a map of projects, which highlights each group of projects, by type. Any of the three main GIS packages would have dynamic segmentation ability to generate a route for arc sections helped in identifying projects where the project limits does not end at a node. This solved the problem of having a limited ability in depicting projects accurately on the street network. Dynamic segmentation also allows for representing overlap projects, which partially or totally share the same road segment.

5.2.5 Buffer Analysis

Using GIS, buffers are created around each project representing the impact area. In GIS, the links located inside the project's impact area (buffer) can be captured, then, travel timesaving can be calculated from the difference in time, before and after the project's construction. This process involves incorporating the travel demand analysis data into the attribute file, which is transferred from GIS to a date base application (i.e., Access, Oracle..etc.) to undertake the calculations required. The benefits of GIS in this process is that it allowed for generating the buffers required for each individual projects and identification of the different roads located inside the impact area. Figure 13 shows the road network for the capital city of Riyadh.

5.2.6 Deficiency Analysis

The deficiency analysis process is utilized to highlight streets where demand exceeds capacity. GIS is used in identifying deficient facilities. Incorporating the link volumes resulting from the travel demand forecasting into the network attribute table in GIS. Using GIS statistics capability, the relationship between the link's capacity and the forecasted volume can be calculated. Links are then colored based upon the severity of demand to capacity ratio and presented on maps. These maps can be the basis for identifying roadways that require improvement to accommodate future demand. Figure 14 Shows a sample map used in deficiency analysis.

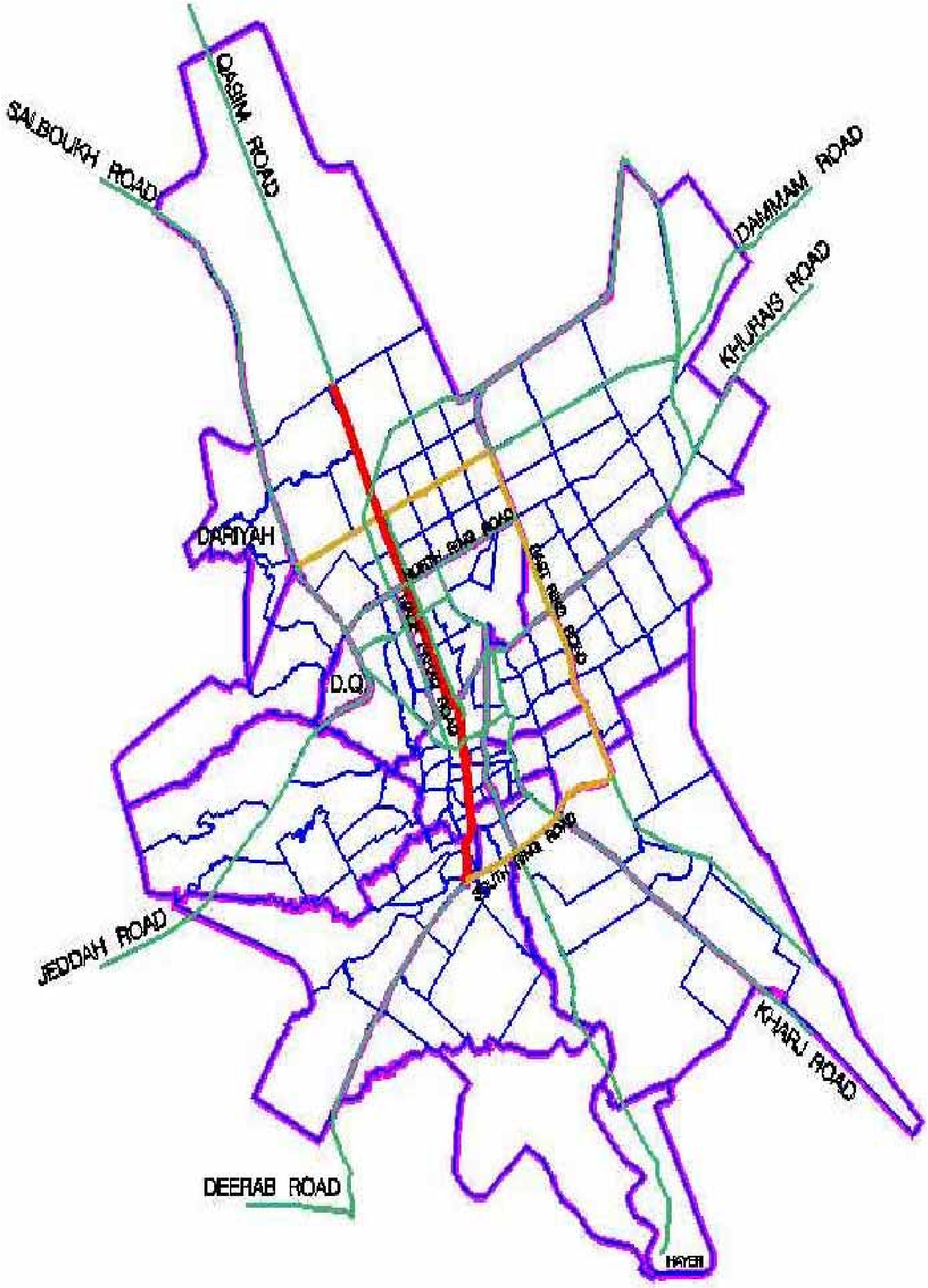

Figure 13: Road Network for the capital city of Riyadh, (*source ref.12*)

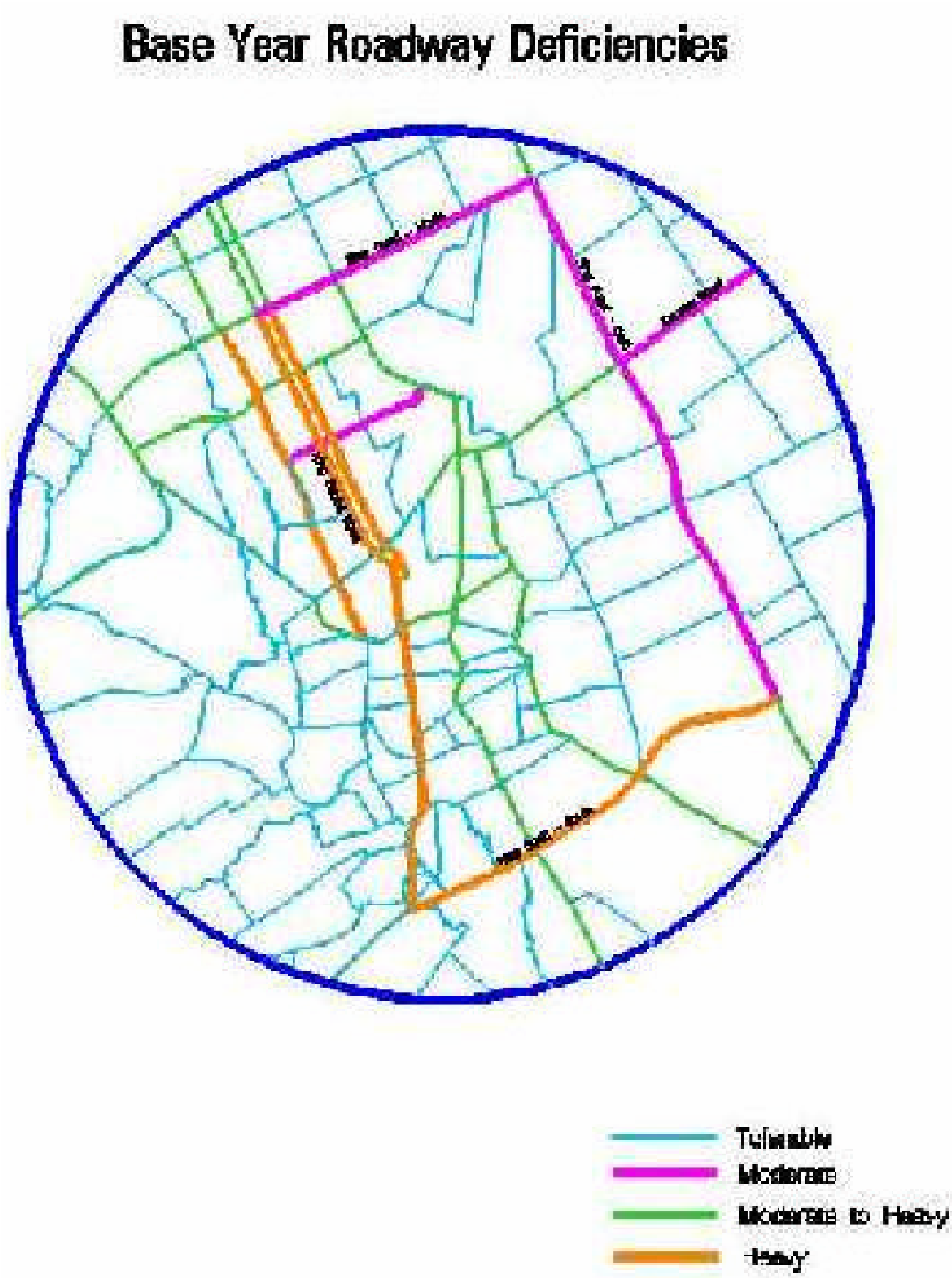

Figure 14: Example Deficiency Analysis Map, (*source: ref. 12*)

From the above figure (figure 14) it was evident that GIS in its tracking road deficiencies led to the conclusion that the major highway of King Fahd Road, Olaya main road, Takhassusi road and ring road-south recorded the heaviest traffic. This was based on the observed data, which was linked to a database that enabled the researcher to manipulate it based on the international standards of road capacities. Khurais road on the eastern section of the city indicated a more moderate to heavy road deficiency except of its east of the Ring Road-East where road deficiency was more on the moderate side. The rest of the roads were mainly on the tolerable side.

5.2.7 Discussion

The deployment of GIS applications in transportation planning has been taking its way in the transportation agencies in Saudi Arabia, particularly in Riyadh. GIS packages have been used in Riyadh's municipality and its sub-municipalities. However, not all capabilities of GIS are utilized, for example GIS-T models could be used to help decision makers to make electronic decisions and thus predict outcomes prior to any actual decision on the ground which leads to more economically optimum decisions and reasonably predict the consequences. Therefore, still GIS application does not have major role in the transportation planning process in Saudi Arabia. Also, there is alack of published projects that show the use of GIS in this field. Local data are not readily available; more efforts are exerted from different organizations to create their own data. Moreover, some GIS data and services are distributed on the internet. ADA has developed a site allows its visitors to brows some browsing Riyadh map, they can search for streets or locations, besides some services.

6. Recommendations

Although there is a broad application of GIS in transportation, there is a lot of value to GIS that is not yet being fully explored in transportation analysis and planning (Sutton *et al.* 2004). The following are some recommendations for the improvement of the GIS applications in transportation:

- Improving communication of GIS-T programs and exchanging information about what is happening in the GIS-T sector.

- GIS is becoming broader based in geospatial information systems that include the application of the global positioning system and the integration of remote sensing technology. How can transportation benefit from these developments?
- The use of GIS in historical data analysis, such as trends in automated passenger counts, boardings and alightings, and demographic analysis of transit passengers.
- The implications of data exchange standards. How will this affect data sharing and integration, data quality, and validation?. There are several standards that affect transit and some confusion within the transit industry as to which standards to apply. Clarification and guidelines for standards implementation are needed.
- Often the costs and benefits of GIS in transportation projects are hidden and difficult to define within budgets and organizational arrangements. The growth of GIS and its significant cost needs more examination of its financing and economic impacts.

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Appendix A:

Source of case study 1: Transportation System Management for Madurai City Using GIS

Appendix B:

Source of case study 2: Application of GIS in Transportation Planning: The case of Riyadh, the Kingdom of Saudi Arabia