Geographical Information System in Transportation Planning

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Abstract:

To satisfy transport infrastructure requirement in a country in consonance to its developmental pace, decisions must be based on more reliable, update, relevant, easily accessible and affordable information. Geographic information system for transportation has now emerged as the technology with considerable potential for achieving dramatic gains in efficiency and productivity for multitude of traditional transportation applications. GIS application has relevance to the field of transportation engineering due to 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. The paper thus reviews the suitability and applications of Geographic Information Systems (GIS) technology for managing the transport structure in the country.

1. Introduction

The road network in India is huge with more than 3.01 million kilometers of road length with 34608 km of National Highway, 128622 km of State Highway and informal network of 2737080 km, operated in vastly different social, economic and climatic environments. The planning and management of such a huge network in the country has been primarily done at two levels i.e. national and local level. The national level planning in the country is broad based and is done using some macro level data like area, gross domestic product etc., whereas local level planning is problem specific and confined to a vicinity of a few metropolitan cities. The road network planning based on the travel demand requirements in the country could not be adopted merely due to lack of relevant data needed for it (MOST, 1984).

The major planning in different aspects of road network can be attributed to the lack of availability of large volume of data required for this purpose. Even if this data is made available, the next problem is how to manage and access that data. The valuable information related to existing transport infrastructure is scattered all over the country at different organizations. The attribute data of NH, SH and MDR network is available in pieces in different organizations of the state level system, and it is rarely utilized effectively by planners. At present any exercise on sufficiency of the existing network in the regional context or nation wide plan generation for primary network like expressway cannot use any of the existing data. Thus practically the present available data at a large number of locations in all possible formats are waste and resources spent for collection and maintenance of this data is draining the economy as a routine ritual and not fulfilling the objectives.

Highway networks face deterioration problem due to the lack of funds for infrastructure. The adoption of newly emerging technologies such as Geographic Information System (GIS) can help to improve the decision making process in this area for better use of the available limited funds. Geographical

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.

The use of GIS for transportation applications is widespread. Typical applications include highway maintenance, traffic modelling, 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.

The paper thus reviews the suitability of Geographical Management System (GIS) technology for managing the transport infrastructure in the country.

1.1 Information System for Transportation

Many development projects have serious dependence on transport network**.** Authentic information on the transport infrastructure is fundamental requirement for many decision making process; therefore information is required to be reliable, updated, relevant, easily accessible and affordable. Better information doesn't guarantee better decision-making capability but its absence precludes it. This demand for information requires new approaches in which data related to transportation network should be identified, collected, stored, retrieved, managed, analyzed, communicated and presented. The road transport related data in particular involves activities like traffic counting, sign inventories, accident investigation, recording of construction and maintenance projects and funding, right of way surveys, bridge inventories, pavement condition surveys, geometry design inventories, and other data collection and maintenance activities. These activities are mostly uncoordinated within the organizations and across the organizational boundaries. Because of lack of co-ordination or of narrow concept of data use and application, data collected foe one purpose is rarely usable for others. If two users need the same data or very similar data, the data is often collected twice. However, if the data is integrated properly by using the appropriate referencing system concept it can be put to maximum use for transportation as well as for many other purposes. Considering the complexities in developing, updating and processing of the transport related data and the declining trend in cost of data management and storage facility there is and urgent need to adopt new concepts and technologies for designing and developing the information resource management of transport infrastructure in the country. Therefore, the development in the field of information technology such as GIS Expert System and Database Management Systems are especially relevant to the field to transportation engineering.

1.2 Role of GIS

Geographic Information System (GIS) represents a new paradigm for the organization of information and design of information systems, the essential aspect of which is use of the concept of location as the basis for the structuring of information systems. 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 socio-economic data with transport network database for wide variety of planning functions.

2. GIS FOR TRANSPORTATION ENGINEERING

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.

Transportation Planning generally consist of a number of individual modules, often operated independently of one another. These modules include construction quality control, pavement management, maintenance management, bridge management, traffic systems management (traffic operations management for traffic corridor analysis, highway construction-oriented rerouting, hazardous materials routing, incident management, and safety elements management) roadside safety appurtenances, and accident data.

Thus, 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 for transportation (GIS-T) is the union of transportation information system (TIS) and GIS. The biggest advantage of GIS-T to various transport organizations is its potential for data integration. The data referenced to transportation network as well as many other stand-alone databases of the past like bridge inventories; signage location, accident record and other safety data; traffic volume and other operational data. Other data types such as administrative, land use, demographic, environmental, resource, terrain, and subsurface data can also be integrated. The main functions of GIS useful for solving transportation problems are editing, display, measurement, overlay, dynamic segmentation, surface modeling, raster display, and analysis, routing and links to other software.

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.

2.1 Application Development

The three broad functional areas – planning, management, and engineering – will be used to categorize existing and future GIS-T applications. Planning applications often do not need highly precise locational data. Thus they can be developed at the statewide level with a grid network that covers the entire state. The statewide network will be primarily useful for long-range strategic level planning with infrequent updates.

Management applications often require more detailed locational data that are available at the regional or district level. A linear network would typically encompass a corridor or sub-area of interest. For a sub-area, a grid network may be required.

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).

2.2 Transportation System Attributes

Transportation system attributes can be grouped into six categories 1) physical, 2) traffic, 3) travel, 4) freight, 5) operations and maintenance, and 6) financial.

Transportation involves the interaction of *supply* (physical attributes) and *demand* (traffic attributes). Analysis of the interaction between supply and demand is enhanced by travel attributes that explain why traffic exists at one location and not another. The operations attributes provide information on the control of the transportation system and how the system is maintained. Finally, financial attributes are needed to address resource allocation questions.

Financial attributes cover a wide variety of costs, which can be grouped into the three main categories of construction, maintenance, and vehicle operating costs.

2.3 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.

2.4 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.

3. GIS APPLICATIONS IN TRANSPORTATION SYSTEMS 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. The application areas of GIS to transportation spans over all the traditional areas of responsibility of a highway agency (Singh, 1999).

3.1 Pavement Management

Pavement Management System (PMS) contains three primary components: data collection, analysis and updation. 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 programme, 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.

3.2 Traffic Engineering

Congestion management programmes 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.

3.3 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.

3.4 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.

3.5 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. CONCLUSIONS

GIS provide the uniform environment in which the data for numerous planning purposes can be integrated. GIS technology provides the core framework for an integrated highway information system. The developed database can be further supplemented with new information as and when it is available. So, the database keeps on evolving, which is otherwise not possible to compile at one time. The topological information available in GIS database opens the new ways for analyzing the transportation related data for different purposes. Various GIS functionality, spatially the spatial analysis functions and querying capability, are very useful tools for the day-to-day management of the road network by the concerned organizations.

The impact of GIS technology in development of transportation information system and Highway infrastructure management is profound. If GIS technology is exploited to it's fullest extent it will completely revolutionize the decision making process in transportation engineering. GIS is being recognized world over as the most efficient tool for integration of all types of data necessary for transport sector. The huge amount of information related to transport infrastructure in the country could be put together for its most efficient utilization in planning, design, construction, maintenance and management of the transport system. There is an urgent need to organize the existing database compatible to GIS environment and suggest various other new data items, which are considered useful for better planning and management.

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