THE USES AND APPLICATIONS OF GEOGRAPHIC INFORMATION SYSTEM FOR HIGHWAYS DESIGN AND TRANSPORTATION MANAGEMENT IN TRINIDAD AND TOBAGO

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ABSTRACT

Developing and managing an efficient highway and urban transportation system continues to be a challenge to city planners and engineers, more particularly in the less-developed countries. One prominent cause of this problem is deficiencies in the availability and management of the large volume of spatially related data required for planning and monitoring of transportation infrastructure. Geographic Information System (GIS) technology provides the capability for interfacing attribute data with spatial data for various spatial analyses. This capability can yield a cost-effective approach to the planning, utilization, and management of highways and transportation facilities. The paper reviews data management needs for the Traffic Management Branch of Trinidad and Tobago and then, explores the uses and applications of GIS techniques for highways and urban transportation management. Capabilities for interfacing traffic data, environmental data and roadway data with geographic data is highlighted, as well as possible queries which could be generated from such systems for planning, development and research purposes.

1.0 INTRODUCTION

As part of the Traffic Safety Campaign of 1991, the Traffic Management Branch (TMB) of Trinidad and Tobago published the following statistics about traffic accidents in Trinidad and Tobago:

a. In the last ten years over 2,200 persons died on the roads;
b. In the last ten years over 300,000 traffic accidents occurred;
c. Over $4.0 billion has been spent on traffic accidents in the past ten years.

These are rather shocking statistics for a small developing country and they probably represent only a fraction of the actual occurrences. In order to reduce the rate of accident, death, and cost, transportation engineers and planners should seek answers to the following questions:

a. Where on the road did these accidents occur?
b. Which road section has the largest number of accidents?
c. What are the physical and cultural characteristics of this road section?
d. What is the relationship between the type of vehicle involved in the accident and the characteristics of the road?

The answers to these questions would help to arrive at an informed-decision in seeking ways of reducing traffic hazards on the roads. The answers can only be provided with the availability of accurate and up-to-date spatial and attribute data on the geographic, geometric and functional conditions of roads and human activity along the roads.

Data Management at the TMB

The TMB was established in 1977 as a government agency responsible for the design of an "effective and coordinated approach to the development and management of transportation systems" in Trinidad and Tobago. In order to accomplish this task, the Branch undertakes a number of activities, some of which include (TMB, 1990):

a. Monitoring accident statistics with a view to:
   i. compile accident statistics;
   ii. determine and eliminate accident blackspots.
b. To work along with the Highways Division and the Decentralization Section towards the streamlining of a Road Hierarchy in Trinidad and Tobago and development of a strategic transportation plan for the country.
c. To computerize the Branch's filing system as much as possible.

These activities rely heavily on the availability of data. In a study of agencies involved in the collection and use of land-related data, it was found that TMB obtains its data from the following other government agencies: the Highways Division, the Central Statistical Office, the Town and Country Planning Division, the Environment Division, the Protective Services, and through direct field data collection by its own personnel. This wide range of data sources is expected. It however, necessitates the need for standardization and compatibility. The study also identified the following problems in data collection and data management at the Branch: high cost of reproduction services, high cost of data collection, increasing number of sources that must be contacted, unavailability of required data, e.g. spatial data, uncertainty as to the reliability of collected data (Opadeyi, 1990b).

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In addition, it was found that land-related data is collected on a project basis, hence there is no continuity and no historic data which might be required for research and development purposes. Significantly, TMB lacks the necessary technology for monitoring pollution related to transportation activities and for handling spatial data. As in most other government agencies, the Branch is inadequately funded for projects and does not have enough manpower for its research and development activities. It is to be noted that the Branch spends a mere 10% of its annual budget on data collection, 50% on systems development and 10% on providing information services. Working under these manpower and financial constraints, there is no doubt that the Branch cannot operate at optimum and take advantage of new technology in the performance of its activities. These difficulties are directly related to the inefficient transportation management strategies of the Branch. The development of a geographic information system capability within TMB can significantly reduce these short falls to data collection and data management.

2.0 OVERVIEW OF GEOGRAPHIC INFORMATION SYSTEMS (GIS)

GIS is an information system designed to store, retrieve and process spatial and attribute land-related data (Opadeyi 1990a). Its ability to perform spatial analyses using computer technology is responsible for the increasing use of GIS.

2.1 Components of a GIS

The basic components of a GIS are:

a. Hardware (e.g. computer, plotter, digitizer).
b. Software (e.g. operating systems, applications).
c. Data (e.g. maps, satellite imagery, records).
d. Institutions (e.g. users, data sources).

2.2 Uses of GIS

GIS is a set of tools and procedures that allow for the access, sharing, interpretation, use and management of spatial and attribute data. It is used to identify the location of the occurrence of an event, the condition of the event, trends in the occurrence of the event, the spatial and temporal patterns in the occurrence of events, and the modeling of the phenomena that influence the occurrence of events. These capabilities have contributed to the varying uses of GIS by professionals involved in land-related fields. Architects and civil engineers are using GIS for the design and management of construction works. Forestry professionals and environmentalists use GIS to monitor environmental impacts. City planners and land administrators also use GIS techniques to automate traffic planning, property assessment and taxation.

2.3 Benefits of GIS

The increasing popularity in the use of GIS in both the developed and developing countries is due to the apparent ease and timeliness with which it provides response to spatial queries. The digital map of a GIS is easier to revise, share and store than the conventional hard-copy map. The ability to share digital data implies that duplication in the collection and storage of spatial data can be reduced. Common justifications for the acquisition of GIS are (Aronoff, 1989):

a. better storage and updating of data;
b. more efficient retrieval of information;
c. ability to integrate different types of data in a single analysis;
d. more efficient production of information products;
e. rapid analysis of alternatives; and
f. the value of better decisions.

2.4 Data and Database Management Systems (DBMS) in GIS

The collection and management of data is perhaps, the most expensive component in the acquisition of GIS technology. It is reported that data collection and database development consume about 75% of the cost of a GIS. Whereas GIS hardware and software can be purchased off-the-shelf, data collection and management is a life-long activity in the use of GIS. Large volumes of mostly disparate data are continuously collected and stored. It therefore requires institutional arrangements, procedures and standards to ensure continuity, compatibility and comprehensiveness among the various users and uses. DBMS are software packages designed to create, edit, manipulate and analyze collected data. Data are organized or modeled in DBMS using a variety of data models. Three of the most popular models are: hierarchical model, network model, and relational model. The relational database is the most popular of the four and it has become the industry standard. It uses the Standard Query Language (SQL) which uses spoken English-like commands for formulating queries. Masry and Lee (1988), identified the following as the main functions of a DBMS:

a. It hides the physical structure of data;
b. It hides the data access method;
c. It allows concurrent access to the database;
d. It controls data privacy in a multi-user environment;
e. It controls data integrity;
f. It controls data redundancy;
g. It provides an interface for non-programmers.

2.5 Developing GIS Applications

The development process of a GIS application can be conceptualized as follows:

a. Collection and storage of textual or attribute data.
b. Collection and storage of spatial data of natural and built environment.
c. Development of databases, data retrieving mechanism, and cross-referencing capabilities.
d. Development of applications using subject-specific mathematical models and procedures.

3.0 GIS APPLICATIONS IN HIGHWAY DESIGN AND TRANSPORTATION ENGINEERING

Transportation engineering is that part of social engineering that deals with the mobility of people and goods from one place to another. Papacostas (1987) identified a transportation system to consist of three components: the fixed facilities, the flow entities, and the control systems. *Fixed facilities* are the networks of links (roadway, railing track, pipelines) and nodes (intersections, interchanges, transit terminals, harbour, airports) of the transportation system. They provide the basic infrastructure for the system. *Flow entities* are the units that utilize the fixed facilities (motor vehicles, pedestrians, railroad cars). *Control systems* are restrictions and regulations designed to ensure that the flow entities efficiently utilize the fixed facilities (vehicular control and flow control). Fixed facilities are geographical entities. Their selection and design are mostly influenced by natural and cultural features. Human settlement patterns, locations of hills and valleys, and industrial activities are some examples of factors that influence the siting and design of the fixed facilities. These phenomena are geographic entities and can thus be mapped either in the relative and/or absolute positions.

In designing a proposed highway, the first task is route selection. Of the various factors that influence the selection, economic efficiency is given top priority. GIS techniques can be used to choose alternative routes and analyze the economic efficiencies of the alternatives. If digital terrain data of the jurisdiction under consideration is available, it is possible using GIS to obtain a digital terrain model (DTM) of the area. The model will provide a 3-dimensional view of the terrain and hence help in selecting alternative routes using visual skills. Depending on the accuracy of the terrain data, the design process can commence with very little field verifications.

Another task in the design of highways is the geometric design of the proposed links and nodes. Basic components of a geometric design of highways are: cross-section, horizontal alignment, vertical alignment, super-elevation, channelization, and delineation of vehicular paths. These components require a knowledge of the physical condition of the selected routes, the width of the right-of-way, estimated traffic volumes and other analytical parameters. The computation and modeling of these parameters can be built into the GIS software, such that route selection and geometric design can be undertaken under the same platform thereby making revision and updating an easy process.

Depending on the availability of data and mathematical model, it is possible to build applications that will undertake the following analyses:

a. Traffic volume estimates for evaluating geometric improvements.
b. Speed estimates for evaluating geometric improvements.
c. Effect of lane and shoulder widths on travel time.
d. Physical and operational features affecting safety at intersections.

These analyses are not peculiar to GIS, but can be linked through networks and interface to a GIS platform to produce graphical and geographical representations of the results.

4.0 GIS APPLICATION IN TRANSPORTATION MANAGEMENT

Transportation management involves the monitoring of transportation phenomena and decision making to ensure safety and efficiency of services. Urban transportation usually involves solving the following problems: Congestion, peaking phenomena, lack of mobility for certain urban groups, adverse environmental, social and economic impacts etc. These problems require socio-economic data and other land-related data for their reduction, if not elimination. There are four major categories of data required for transportation management: Land use data; population density data; income distribution data; and mapped data of existing transportation routes and networks. GIS provides mechanisms for the integration of these categories of data. Data on the effluent level, traffic volume count, soil permeability and soil quality can be interfaced by geocoding the data to their source. The possibility also exist for the linkage or interface of existing transportation planning models to a GIS software environment, thereby providing for a single integrated planning and analysis platform. Typical transportation phenomena and decisions which can be simulated using GIS are as follows:

a. Percentage of land-use for transportation.
b. Percentage of total parking area.

c. Decision on the placement of traffic signals.
d. Decision of land-use rezoning.
e. Trip generation rates for different types of land-use.
f. Traffic flow map.
g. Relationship between accidents and specific roadside features.
h. Relationship between accidents and geometric design of roads.
i. Dynamic rerouting of vehicles during peak flows.

Examples of Data Elements in Transportation Systems

1. Basic Spatial Data
   Natural environment (rivers, contours, forest, geology);
   Built environment (roads, housing, industries,).

2. Design Data
   Cross-section data;
   Horizontal and Vertical alignment data;
   Super elevation data.

3. Interface Attribute Data
   Land use along road networks;
   Place names;
   Traffic signal;
   Pavement characteristics;
   Income distribution;
   Population and age data.

4. Monitoring Data
   Flooding data;
   Accident occurrence data;
   Pavement Maintenance history;
   Pollution (air, noise) data;
   Land-use change due to transportation facilities;
   Social growth data (car ownership, migration).

Spatial data collection for GIS require the use of modern techniques to facilitate the collection in digital formats. Proven data collection techniques are:

a. Close-range photogrammetry.
b. Satellite imagery.
c. Global positioning systems (GPS).
d. Electronic total station systems.
e. Digitizing or scanning of existing maps.

Examples of GIS Applications in Transportation Management

Existing GIS applications in the field of transportation are few but steadily growing. The Saskatchewan Highways and Transportation Division, utilized the Geo/SQL GIS software to satisfy the following objectives (Chursinoff et al, 1990):

a. To give users the ability to interface geographic information with accident statistics, traffic data, and pavement management information residing on Saskatchewan Highways and Transportation mainframe computer databases.
b. To provide users with a map building tool for highway transportation system applications.
c. To provide users with information retrieval capabilities for textual and geographic information.

The US Department of Transportation is developing capabilities for the integration of GIS and Transportation Analysis. A Strategic Transportation Analysis (STA) decision support system which consists of integrated transportation networks, spatially referenced data bases, GIS software, and microcomputer hardware is being developed for Military Traffic Management Command (MTMC) to provide capabilities for transportation analyses in the continental United States. Two safety-related functions of the system when fully operational are (TRB, 1990):

a. To identify primary and alternative transportation routes that can handle large convoy movements under various emergency scenarios.
b. To identify routes for moving hazardous cargo, simultaneously considering such factors as shipment time, security, accident risk, and population exposure.

5.0 CONCLUSIONS

The use of GIS for the management of transportation systems is value-added to existing transportation management methodology. It enhances existing transportation analysis tools and decision making tasks. It adds spatial representation to attribute data traditionally produced as statistics, reports and graphs. The spatial content, supports visual displays which help to relate transportation phenomena to the natural and built environment. It also provides a geographic coding system for the collection and referencing of traffic survey data, accident report data and other basic field data.

The potential for the use of GIS for highway design traffic management in Trinidad and Tobago is high, with over seven (7) GIS software packages installed in the last three years and with many more about to be acquired. This potential is, however, threatened by two challenges: the non-availability of data and the use of expensive data acquisition techniques. Existing large scale maps are mostly out-of-date and inaccurate. There is no up-to-date land use map for the urban areas. The most recent aerial photographs were produced in 1986 (new mapping programme is to be undertaken before the end of the year 1993). Data acquisition poses another problem. There is no comprehensive and systematic housing numbering systems for a large portion of the peri-urban area and the large squatters settlements. It would thus become difficult to utilize address matching modules available in GIS software. The use of remote sensing technology as a cost-effective data acquisition tool should be actively explored.

REFERENCES

Aronoff, S. (1989) *Geographic Information Systems: a Management Perspective* WDL Publications, Ottawa.

Chursinoff, R. et al (1990) "Implementation of a GIS at Saskatchewan Highways and Transportation" in *GIS for 1990's Proceedings of the National Conference on GIS,* March, 1990. Ottawa.

Creighton, R.L. (1970) *Urban Transportation Planning* University of Illinois Press, Urbana.

Hogan, R. (1990) *A Practical Guide to Database Design.* Prentice-Hall Inc., New Jersey.

Masry, S.E. and Y.C. Lee (1988) *An Introduction to Digital Mapping.* Lecturer Notes No. 56 . Department of Surveying Engineering, UNB, Frederation, NB.

Opadeyi, J.A.S. (1990a) "Planning and Implementation Strategies for the Acquisition and Utilization of Geographic Information Systems in Trinidad and Tobago" in *Proceedings of the 4th. Annual Technical Conference of the Association of Professional Engineers of Trinidad and Tobago*, Nov. 1990, Trinidad.

Opadeyi, J.A.S. (1990b) On-going field study for Ph.D thesis.

Papacostas, C. S. (1989) *Fundamentals of Transportation Engineering* Prentice-Hall Inc., New Jersey.

Spear, B. D. (1990) "DOT Integrates GIS and Transportation Analysis" in *FDC Newsletter* No.12 Fall 1990. FICCDC, Virginia.

Traffic Management Branch (TMB) (1990) "Policy Guidelines for the Traffic Management Branch". (Unpublished report) TMB.

Transportation Research Board (TRB) (1990). *Data Requirement for Monitoring Truck Safety* Special Report #228. National Research Council, Washington D.C.