Chapter-7

GIS-T Applications

Key words: GIS and transportation, matrix operations, SP analysis, network analysis.

In the past, many individual developments, both technological and conceptual led to the rise of Transportation-GIS (GIS-T) especially during 1980s and 1990s. In this chapter, an attempt has been made to review these individual developments which led to the rise of GIS-T, and also to bring out the trends and future directions of research in this most exciting and useful field of GIS endeavour.

7.1 Introduction

Transportation applications of GIS have become increasingly popular in recent years, so much so that they are routinely referred to by the acronym GIS-T. This is mainly due to the fact that to design an efficient transportation system, one needs to collect, manage, retrieve, and analyze a large amount of data, which is not possible with the manual and heuristic approaches prevailing till date. Hence, there is a need for an efficient database management system to handle such large-scale data, and Geographical Information Systems (GIS) is one such efficient system, which has been thoroughly described in previous chapters. But, GIS in transportation is more than just one more domain of application of generic GIS functionality. GIS-T has several data modeling, data manipulation, and data analysis requirements that are not fulfilled by conventional GIS. To quote, Vonderohe et al (1993), “the necessary enhancement to existing Transportation Information Systems (TISs) is the structuring of the attribute databases to provide consistent location reference data in a form compatible with the GIS, which in turn has been enhanced to represent and process geographic data in the forms required for transportation applications.

Now-a-days, there are already many conferences which are fully devoted to GIS-T and even many of the general GIS conferences have special sessions on GIS-T and closely related topics such as infrastructure management. GIS-T is well represented in GIS journals such as computers, Environment and Urban Systems, the International Journal of Geographic Information Science, Geographical Systems, Transactions in GIS, GIS Development, and Geographic Information
There have been special issues of traditional transportation journals devoted to GIS-T and special GIS-T journals such as the *IVHS Journal*. Finally, there are GIS packages like TransCAD, which have been developed specifically for GIS-T, although much of the additional functionality required in GIS-T may also be found in the industry leading generic GIS packages. In short, it is possible to state unequivocally that GIS-T has ‘arrived’ and now represents one of the most important application areas of GIS technology, Maguire *et al* (1993).

### 7.2 Geographic Information Systems and Transportation

The four major components of a GIS, encoding, management, analysis and reporting, have specific considerations for transportation:

- **Encoding.** Deals with issues concerning the representation of a transport system and its spatial components. To be of use in a GIS, a transport network must be correctly encoded, implying a functional topology composed of nodes and links. Other elements relevant to transportation, namely qualitative and quantitative data, must also be encoded and associated with their respective spatial elements. For instance, an encoded road segment can have data related to its width, number of lanes, direction, peak hour traffic, etc.

- **Management.** The encoded information often is stored in a database and can be organized along spatial (by region, country, census units, etc.), thematic (for highway, transit, railway, terminals, etc.) or temporal (by year, month, week, etc.) considerations. It is important to design a GIS database that organizes a large amount of heterogeneous data in an integrated and seamless environment such that the data can be easily accessed to support various transportation application needs.

- **Analysis.** Considers the wide array of tools and methodologies available for transport issues. They can range from a simple query over an element of a transport system (what is the peak hour traffic of a road segment?) to a complex model investigating the relationships between its elements (if a new road segment was added, what would be the impacts on traffic and future land use developments?).

- **Reporting.** A GIS would not be complete without all its visualization and data reporting capabilities for both spatial and non-spatial data. This component is particularly
important as it offers interactive tools to convey complex information in a map format. A GIS-T thus becomes a useful tool to inform people who otherwise may not be able to visualize the hidden patterns and relationships embedded in the datasets (potential relationships among traffic accidents, highway geometry, pavement condition, and terrain).

Information in a GIS is often stored and represented as layers, which are a set of geographical features linked with their attributes. In Figure - 7.1 a transport system is represented as three layers related to land use, flows (spatial interactions) and the network. Each has its own features and related data.

![Figure 7.1: Representation of Transportation System](image)

**Figure 7.1: Representation of Transportation System**

### 7.3 Historical Development of GIS-T

The concept of GIS traces its root back to a handful of research initiatives in the US, Canada and Europe during the late 1950s. It is widely acknowledged that the first real GIS was the Canada Geographic Information System set up for the Canada Land Inventory. As far as GIS-T is
concerned, many individual developments, both technological and conceptual, have contributed to its rise. Technologically, GIS-T, like GIS as a whole, benefited from developments in management information systems and database techniques in general, and relational databases in particular. The development of ‘stand alone’ packages for carrying out specific operations such as shortest path analysis and location-allocation modeling (Rushton et al, 1973), and more recently the McTrans programs (University of Florida, Transportation Research Center) all contributed to the development of GIS-T. On the hardware side, the development of powerful and low cost desktop computing hardware assisted the introduction of GIS-T into even smallest government departments of transportation.

Many conceptual developments were also important in aiding the rise of prominence of GIS-T. These developments included works in operations research and programming, which led to new algorithms for shortest path analysis, routing procedures, solving the ‘transportation problem’ of linear programming, and the dynamic segmentation of links within the GIS-T, (Church and Sorensen, 1996). Frequently, these algorithms became embedded first in the stand-alone packages such as Ostresh’s (1973) shortest path analysis routines and then in the fully developed GIS and GIS-T packages such as ARC/INFO and TransCAD, respectively. Equally important was the development of a systems approach to transportation planning (Stopher and Meyburg 1975, Wilson 1974) and the so-called four-step model of trip generation, trip distribution, modal split and network assignment, as discussed in the previous chapter.

One of the forerunners of the original GIS-T applications was the Geodata Analysis and Display System (GADS) which was developed by the IBM Research Division in the mid 1970s to help solve problems such as police beat and school boundary design, (Keen and Morton, 1978). While GADS was not typical of the later generation GIS-T packages it did incorporate such datasets as traffic pattern and transportation infrastructure; it was essentially a rudimentary GIS. Shortly, after this, and totally independent of the American work, research in Sweden led to the establishment of a road data bank which was used for transportation planning (Bydler and Nilsson, 1977). In the Swedish system many of the fundamental problems and challenges in the development of GIS-T, such as the node and link referencing system and the data content of the system, were addressed and resolved for the first time.
The above represents a brief history of some of the more important milestones which led to the development of GIS-T in the 1980s and 1990s. A more detailed account may be found in Simkowitz (1988).

7.4 The Structure of a GIS-T

7.4.1 The Relational Database Management Model

Today most GIS-T uses a relational database model for the storage of attributes. Grayson (1991) discusses the use of an external relational database management system (RDBMS) which uses Structured Query Language (SQL) in conjunction with the ARC/INFO GIS. This approach is becoming less necessary as many GIS and GIS-T packages incorporate their own RDBMS. Other database models such as the flat files have been used but they became less popular in the 1980s because of the greater conceptual and operational elegance of the relational database (Healey, 1991). Maguire et al (1993) describe the RoMIS system developed by Oracle Corporation as part of their highways application package and also the HERMIS system developed for the Ingres RDBMS. While these systems allow for the efficient storage of transportation network and attribute data, they do not provide any geographical analysis or mapping capabilities. Such capabilities are provided by ESRI’s ARCHIS (ARC/INFO Highways Information System) which also includes an interface to Oracle’s RoMIS.

7.4.2 Spatial Databases

Bydler and Nilsson (1977) were among the first to address the complexity of developing a location referencing system for a GIS-T. Goodwin et al (1995) provides a summary of the more common systems. These include: link Ids using either a planar or non-planar graph representation; linear referencing systems where location is specified as distance from an established node or even a non-topologically significant point along the road (Goodwin et al, 1995 note that the USA is working towards a national standard for a linear referencing system); coordinate systems (Scarponcini, 1995 describes seven different coordinate systems and two different datum in use at the Minnesota department of transportation); street addresses (which
frequently suffer from the problem of ambiguity because similar names are located in close proximity to one another), and finally cross street matching which defines points as offsets from a given node and segments as the difference between two offsets.

### 7.5 Essential Operations and Capabilities Required for a GIS-T

A state-of-art review of the important capabilities of a GIS-T has been done by Nyerges (1989).

#### 7.5.1 General GIS Operations Applied to Transportation-GIS

Many of the operations commonly found in commercial GIS-T packages or systems being run by municipal governments or private firms (e.g. trucking companies) would incorporate the standard capabilities to be found in any GIS. These operations include data editing, display and spatial and conditional search functions.

One standard editing feature that is especially useful in GIS-T is the ability to manipulate existing link attributes to produce entirely new attributes which have applications in transportation planning. Thus it should be possible to divide the arc length by the speed limit in order to estimate travel time (Rowell, 1996). The ability to edit data spatially is essential. For example knowing the number of individuals with particular socioeconomic characteristics who live within walking distance of a light rail transit station would help the transportation planner to estimate the potential ridership. Display capabilities should allow for the import of raster images as background information for the vector transportation database, thus allow users to orient themselves to the real world.

Buffering capabilities are also a commonplace feature in generic GIS but they are particularly important in GIS-T for determining the accessibility of population groups close to transportation routes and services and for determining the environmental and noise impacts of these facilities (Love, 1984; Aultman et al, 1997). It is also important to be able to combine spatial searches and conditional queries within a GIS-T. For example, all narrow roads within 20 miles of a chosen feature should be easily obtainable. Address geocoding is another critical feature for many GIS-T applications (Arthur and Waters, 1995). Finally, the GIS-T should have report generating
capabilities. These are important for accident analysis and road maintenance (Bydler and Nilsson, 1977).

7.5.2 Matrix Operation in GIS-T

Generic GIS packages usually store attribute data in the tabular form associated with traditional spreadsheet and database technology, which is commonly known as the data view (Waters, 1995). In a GIS-T an equally useful form of storage is the matrix in which both rows and columns represent the same set of geographical features, either points such as cities or areas such as traffic analysis zones (TAZs), (Nyerges, 1995). The rows are usually regarded as the origins and the columns the destinations. Thus each element of the matrix can store such information as traffic or commodity flows, travel time or distance measures, and migration patterns. This is known as the matrix view.

Because such matrices are the basis of many forms of analysis in transportation research, Taaffe et al (1996), the GIS-T should be able to create, modify and edit such matrices. Traditionally such matrices are square but some GIS-T packages such as TransCAD allow user to select sets of columns, which may not be identical to the rows, and thus rectangular matrices are also possible. One form of display that is common in transportation research is a map of desire lines, portraying the flows from one zone to all other zones. This is also used in location-allocation modeling to show the allocation of users to a facility. The ability to create such maps directly from a matrix view is a useful feature in any GIS-T. The GIS-T user should be able to edit cells, rows, columns, ranges of cells, or indeed the entire matrix in a single operation. The user should be able to perform the full range of mathematical operations on one or more of cells in the matrix or to apply a formula to the selected cells. It is helpful if the GIS-T package can switch automatically between the data view and the matrix view. Figure - 7.2 shows a typical matrix created using GIS tool.
Figure - 7.2: Typical Matrix (City Distance) Constructed using GIS

7.5.3 Various Modeling Procedures

7.5.3.1 TIGER:

By far the most prolific network structure for GIS-T applications has been the model accepted by the U.S. Bureau of the Census for its Topologically Integrated Geographic Encoding and Referencing (TIGER) files. The TIGER model had developed from some earlier network data models, and it was marked by its adherence to the principle of planar enforcement. Planar enforcement simply means that all lines in the network are forced into a single plane, and all intersections of lines are defined in that plane. The planar enforced TIGER model presented several difficulties. First, many transportation applications are not concerned with the polygons
that may have transportation features as their boundaries. It is the transportation features themselves that are of interest. Secondly, the planar enforcement that was needed to generate polygons also had the effect of splitting transportation features into many small segments whenever two features crossed in the plane. Therefore, there were many “intersections” in the network data structure that didn’t correspond to any actual intersection in the transportation network at all.

7.5.3.2 Shortest Path Analysis (SPA):

SPA is an essential precursor to many GIS-T operations. It is critical for route location models for determining the minimum environmental cost route (Lee and Tomlin, 1997; Thirumalaivasan and Guruswamy, 2000), for determining allocations in a location-allocation model, for trip assignment in transportation planning models, Nyerges (1995), and for automatic vehicle dispatch systems (AVDS). Densham (1996) discusses the importance of SPA routines within his visual interactive location system, which is part of an interface with the TransCAD GIS-T. A major concern in the recent years has been the size of problems, which can be handled by existing algorithms and the solution speed. Zhan (1996) has explored the use of fast shortest path algorithms on extensive road networks.

Shortest path algorithms in a GIS-T should be highly flexible in order to handle the many subtleties of the real world. It should be possible to solve the problem for one origin and one destination or for many origins and many destinations. The GIS-T should be able to store a variety of cost and other variables for each link in the network. Shortest paths in terms of time, distance, and cost may all be relevant. The number of lanes, their height and width, and restrictions such as those on hazardous materials should all be incorporated into the calculations. The more sophisticated GIS packages (e.g. ARC/Info and TransCAD) allow impedance functions to be specified for turns of various types, traffic lights, on-off ramps, and other traffic controls and management devices. Algorithms for handling some of these features of the real world were originally developed in the 1960s, Kirby and Potts (1969), although much more comprehensive procedures have been developed, Ziliaskopoulos and Mahmassani (1996) which are likely to be quickly incorporated into standard GIS-T packages. Behavioural work on
specifying relevant attributes for route choice is reviewed by Bovy and Stern (1990). Figure - 7.3 shows typical shortest path analysis solved using GIS software.

![A Shortest Path Analysis Problem in GIS Tool](image)

**Figure - 7.3: A Shortest Path Analysis Problem in GIS Tool**

7.5.3.3 Vehicle (VRo) & Arc Routing (AR)

As also discussed in previous chapter, vehicle routing problem includes the development of routes or tours for deliveries and/or pickups from one or more depots (warehouses) at one or more stops (delivery or pick-up points). Such problems become more complex when there are time constraints at either the depots or stops or both and when the service times are variable. In some problems vehicle capacity is a serious constraints (e.g. delivering gasoline/petrol to a filling station) whereas in other applications this is not the case (e.g. delivering a pizza). TransCAD and some very few packages can handle most of these real world complexities but not all of them - such as mixed fleets, Wirasinghe and Waters (1983), mixed products and open-ended tour. In these cases, either the user can interface their own customized software with the GIS-T or they can ask the GIS-T vendor for a customized solution.
In the arc routing problems the GIS-T user is attempting to find routes which will allow for an optimal (or at least an efficient) transversal of a set of arcs in the transportation network. Applications include bus service and any residential delivery, pick-up or monitoring systems such as mail delivery, solid waste collection, or meter reading, respectively. One of the aims of such algorithm is to minimise the amount of ‘deadheading’ which is the distance from the point at which the service is completed back to the bus depot, mail sorting plant, or other base facility, Waters *et al* (1986). Real world variations which a GIS-T should be able to handle, include situations: where certain links may require service because they perhaps lack houses; where service is required only on one side of a street; and where multiple passes may be required by street cleaning vehicles. As with VRo problems there may be peculiar constraints such as time of day restrictions, which may require customized solutions.

### 7.5.3.4 Spatial Interaction and Gravity Models

The gravity model is still used despite the limitations noted by Wilson (1974), although newer forms of spatial interaction models such as the entropy maximising model popularised by Wilson have largely replaced the more simplistic gravity model. GIS-T packages are now incorporating these procedures as standard operations. Spatial interaction models are increasingly being used as the basis for non-emergency applications of location-allocation models (Birkin *et al*, 1996; Oppong, 1992).

### 7.5.3.5 The Urban Transportation Systems Planning (UTSP)

The four-step UTSP process of trip generation and attraction (how many trips?), trip distribution (where do they go?), modal split (by what travel mode do they move?), and traffic or network assignment (which route do they take?) is almost universally used in transportation planning (Nyerges, 1995; Pas, 1995; Taaffe *et al*, 1996) and a GIS-T package should include procedures for facilitating this process.

The aim of trip generation models is to predict the number of trips produced by each origin zone or region. This task can be handled in many ways. The GIS-T analyst has to make choices concerning the units of analysis, specifically, whether vehicle or person trips are being modeled.
and whether to work at household or individual level (Caliper Corporation, 1996b; Wilson et al., 1974). Trip distribution models are used to predict the flow values in the transportation zone, origin-destination matrix. Modal choice can be determined either at the zonal (aggregate) level or at the individual (disaggregate) level. Estimation procedures may involve either revealed or stated preference, Louviere (1988) and these can be modeled using popular choice such as multinominal, binary, and nested logit models. Akiva and Lerman (1985) and Horowitz (1995) provide comprehensive accounts of these procedures. Traffic assignment models are used to allocate traffic volumes to the network based on the different strategies, a sophisticated GIS-T should allow for a variety of traffic assignment strategies. TransCAD employs the following strategies: all-or-nothing assignment; incremental assignment; capacity constraint assignment; user equilibrium assignment; stochastic user equilibrium; and, finally, a system optimum assignment.

Although it implies that the four-step model is strictly sequential, in practice the process is usually iterative: in particular, the output from the traffic assignment may be used as input to the earlier parts of the model (Nyerges, 1995; Miller and Storm, 1996). In addition, the GIS-T should be used to evaluate the efficiency and effectiveness of the forecast in terms of system parameters such as performance, safety, level of service, environmental concerns, and financial considerations.

7.5.3.6 GIS in Land Use Modeling

GIS is an enabling technology for land use modeling, and typically are either linked to or is used to feed data to most current land use models. This useful connection between GIS and land use models was recognized early on. One of the first uses of the SYMAP, a computer mapping software was to visualize the outputs of land use simulators.

Although none are in widespread use, there are many land use models that have been developed. Thirteen are described by Wegener (1995). Many of the more recent models have been linked to some form of GIS for gathering inputs or the presentation of results. The California Urban Futures Model (Landis, 1994) is built upon a GIS platform, and predicts housing developments for sites; however, it does not treat transportation as a determinant of land use. In models that do
include transport, both zonal (polygonal) and grid cell structures have been used, and historically most models were aggregate in nature, as were the prevalent transport forecasting models in use. In general, land use models have not been very detailed geographically, and tend to be coarser in detail than the transport models that are used. There are computational limits, and some data may not be available at more detailed geographic scales (Green and Flowerdew, 1996).

With the maturation of choice models, land use models are becoming more disaggregate and behavioral in nature, and will require and benefit from the greater geographic detail that GIS technology can provide. For example, the UrbanSim model development effort incorporates disaggregate data which is aggregated to a grid layer with square cells that are 150 m on a side. Parcel-based land use models can be envisioned, which may be the most natural level for modeling.

GIS technology offers the prospects of providing great volumes of data for modeling from existing data systems and tools for obtaining and creating other data needed for land use models. Aerial photography and remote sensing can provide measurements of variables that are important but are not captured in the municipal GIS. Buffering and polygon overlay can be used to create new variables. A GIS has many facilities for managing spatial data of diverse types, and thus offers useful data management for the entities of interest in a land use model, be the roads, households, residential, dwellings, land use polygons, shopping centers, or employment sites. Any data of interest can be associated with these polygons, lines, or points.

### 7.5.3.7 Freight Modeling

The scale independence of a GIS-T based modeling system has facilitated national and inter-regional freight transport model applications. Among these are multimodal models that include shipment by truck, rail, air, and sea. In USA, GIS-T (TransCAD) has been used to synthesize modal freight networks and apply a traffic model for freight modeling for capacity analysis. Extensive use of GIS-T technology was made to integrate state level data sets, national data sets, freight data, and traffic information in a consistent network. Figure 7.4 shows typical freight demand analysis.
7.5.3.8. Public Policy Making

In the policy making process, different studies can be carried out using GIS. One of the examples of this is freight traffic analysis using GIS. This includes integrating truck count data that can be visualized with GIS in a number of ways: by volume, by percentage of total traffic and by percentage growth. This type of data can be used to evaluate truck impacts and design mitigation measures such as designing truck routes, and where to impose truck restrictions.

Likewise GIS are an especially important tool when environmental impacts have to be estimated. These data have spatial extents, so overlaying them with traffic volumes in GIS is an excellent method. Another important issue in public planning is to find patterns in the locations of logistic centers for an optimal planning of public infrastructure for freight transport. These GIS based routing systems can also be used to evaluate the impacts of major incidents that may close down a section of highway.
7.6 Some Specialized Studies Done using GIS-T

Following are some of the examples, illustrating the studies done using GIS-T. They can be broadly classified into, Transport Management Systems, Travel Demand Modeling, Route Planning, and Other Studies.

7.6.1 Transport Management Systems Studies

Many studies have been attempted in GIS-T environment. Simkowitz (1990) points out that a pavement management system (PMS) should address all aspects of the pavement management process from planning and programming through project development and implementation. Simkowitz shows how GIS technology can be used to expand and enhance each of these PMS components. All reported concepts and results have been incorporated into TransCAD, the GIS for transportation software. His conclusions are that the coupling of appropriate GIS technology with stand-alone PMS can result in a greatly enhanced PMS process and also that TransCAD has all the tools for comprehensive PMS/GIS. Partheeban & Santhakumar (1999) described the development of a database for highways around Tiruchirapalli, India (GIS/HAT) using GIS developed in Visual BASIC language. They have tried to present GIS in VB as a viable alternative to the existing GIS software, which are costly to be purchased by planners from developing countries. Kharola and Gopalkrishna (1999) have presented GIS as a powerful analytical tool and discuss its introduction into urban transport undertakings especially with regard to fleet management. Singh (1999), developed the GIS database in TransCAD and used it for the planning and management of regional road network. A study region of five districts around Mumbai Metropolitan Region was considered for this purpose. The objective functions of his study were: a) to develop the GIS database structure for the regional road network based on the organizational hierarchy of the PWD in the country, and b) to develop GIS based procedure for road network management, rural road planning and, road safety analysis. The main drawback with his work is that the database is based on the secondary data obtained from PWD, which is incomplete and inaccurate at many places. Dueker and Butler (2000) developed a framework and principles for sharing transportation data, both of which are based on an enterprise GIS-T model that defines relations among transportation data elements. The data model guards against
ambiguities and provides a basis for the development of the framework and principles for sharing transportation data. A model to synchronize the management and query of temporal and spatially referenced transportation data in GIS has been described by Sutton and Wyman (2000). The model employs a method referred to as dynamic location, which facilitates spatial intersect queries from geographic shapes without the use of topological relationships.

7.6.2 Route Planning Studies

Lepofsky et al (1993), describes the methods employing GIS-T that can provide the capability to perform transportation hazard analysis and incident management. Incident management considerations include those of emergency response deployment and rerouting to bypass the affected area. Transportation hazard analysis also addresses dynamic routing and emergency preparedness in the case of hazardous-materials transport release, and involves comprehensive risk assessment and evacuation planning. The paper concludes with a discussion of how the GIS-T approach to incident management may be extended to address dynamic management in an intelligent-vehicle-highway-system environment. Sadek et al (1999) developed a decision-aid tool using GIS for multicriteria evaluation of route alignments. Possible alignments are evaluated based on community disruption and environmental, geotechnical and geometric design criteria. Results of the case study demonstrates the advantages of the decision-aid tool and highlighted its potential in providing a quick, multicriteria screening evaluation of possible route alignments. Thirumalaivasan and Guruswamy (2000) used the route module available in Arc-Info (a GIS based software) to find optimal routes between two given points for emergency services, such as ambulance and fire services, based on minimum travel time criteria. Southworth and Peterson (2000) describe the development and application of a single, integrated digital representation of a multimodal and transcontinental freight transportation network. The paper focuses on the routing of the tens of thousands of intermodal freight movements reported in United States Commodity Flow Survey.

7.6.3 Travel Demand Modeling

Miller and Storm (1996), reports on the development of a prototype geographic information system design to support network equilibrium-based travel demand models, which is an attempt
to advance the standard practice of sequential approach. The key features of GIS design include
(a) realistic representation of the multimodal transportation network, (b) increased likelihood of
database integrity after updates, (c) effective user interfaces, and (d) efficient implementation of
network equilibrium solution algorithms. Souleyrette and Anderson (1998) presented tools and
recommended steps for developing urban transportation models using desktop GIS. Taking the
case study of Ames, Iowa, these procedures and tools are shown to facilitate integration of
spatially referenced data for efficient model development. An integrated transit-oriented travel
demand modeling procedure within the framework of GIS has been presented by Choi and Jang
(2000). Focusing on transit network development, this paper presents both the procedure and
algorithm for automatically generating both the link and line data for transit demand modeling
from the conventional street network data using spatial analysis and dynamic segmentation. Rao
(2000) has done a comparative study of various traffic assignment techniques using TransCAD.

7.6.4 Other Studies

Pathan et al (1993), described the results from a study about growth trends of the urban areas in
the Bombay metropolitan region using multi-date remote sensing data and ARC/INFO GIS
package. The spatial growth trends are examined in relation to the population and the population
density has been computed for different periods. Based upon these densities, the extent of land
required for urban development for the year 2001 has been calculated. Soni et al (1996)
described some basics of GIS technology and its applications and suitability for transportation
engineers. Cesar and Darcy (1998) described a new methodology for performing travel time
studies using Global Positioning System (GPS) and geographic information system (GIS)
technologies. The data collection procedure uses GPS receivers to automatically collect time,
local coordinates, and speed at regular sampling periods, for example every one second. The data
reduction procedure filters and aggregates GPS data to compute travel time and speed along
highways. The data reporting procedure uses a GIS-based management information system to
define queries, tabular reports, and color-coded maps to document travel time data along these
highway segments. O’sullivan et al (2000) investigated the application of existing desktop GIS
to the assessment of accessibility by public transport. Two approaches to the measurement of
accessibility- aggregate accessibility measures and the space-time geography framework- were described. It has been suggested by authors that isocrones (lines of equal travel time) are a natural way to combine these approaches in a GIS setting. Thill (2000) placed the concept of GIS-T in broader perspective of research in GIS and Geographic Information Science. He emphasised on the requirements specific of the transportation domain of application of this emerging information technology as well as on core research challenges. Ziliaskopulos and Waller (2000) developed an internet-based GIS that brings together spatio-temporal data, models and users in a single efficient framework to be used for a wide range of transportation applications- planning, engineering and operation. They also discussed the implementation issues and necessary models needed to support the system. Xiong (2000) described a three-stage matching algorithm (node matching, segment matching, and edge matching) that combines bottom-up and top-down procedures to carry out the network matching computation. Kwan (2000) describes several GIS-based three-dimensional (3D) geovisualisation methods for dealing with the spatial and temporal dimensions of human activity-travel patterns at the same time while avoiding the interpretative complexity of multivariate pattern generalisation or recognition methods. Bachman et al (2000) presented a GIS-based modeling approach called the Mobile Emission Assessment System for Urban and Regional Evaluation (MEASURE). MEASURE provides researchers and planners with a means of assessing motor vehicle emissions reduction strategy. The authors have discussed the benefits and challenges related to mobile source emissions modeling in a GIS framework and identifies future GIS mobile emissions modeling research needs. You and Kim (2000) developed and evaluated a hybrid travel time forecasting model with GIS technologies for predicting link travel times in congested road networks. Taylor et al (2000) described a case study application of developing an integrated GIS-GPS for collecting on-road traffic data from a probe vehicle for traffic congestion studies. Peng and Huang (2000) presents a web-based transit information system design that uses Internet Geographic Information Systems (GIS) technologies to integrate Web serving, GIS processing, network analysis and database management.

Likewise, GIS has been tried for many other applications to transportation like, pedestrian accessibility, highway management, prediction of urban traffic air pollution, regional planning,
road environmental impact, transportation improvement site selection, land use planning, land use-transport planning etc. The following sub-sections describe few of the studies in greater detail.

### 7.6.5 Design and Development of Interactive Trip Planning for Web-Based Transit Information Systems

Peng and Huang (2000) developed a Web-based transit information system that allows transit users to plan a trip itinerary and to query service-related information, such as schedules and routes using Internet Geographic Information Systems (GIS) technologies. A unique feature of the system is that it integrates Internet GIS into the system design so that the user interface is map-based. The user can interact with the transit network and street maps, conducting query, search, and map rendering. The interactive map-based user interface also allows the system to incorporate other information, such as shops, theatres, parks, and other local attractions. This is very important for visitors who may want to explore these sites around their destinations. A path finding algorithm for transit network is proposed to handle the special characteristics of transit networks, e.g., time-dependent services, common bus lines on the same street, and non-symmetric routing with respect to an origin/destination pair. The algorithm takes into account the overall level of services and service schedule on a route to determine the shortest path and transfer points. A framework is created to categorize the development of transit information systems on the basis of content and functionality, from simple static schedule display to more sophisticated real time transit information systems.

### 7.6.6 IMPACT: An Integrated GIS-Based Model for Simulating the Consequences of Demographic Changes and Population Ageing on Transportation

Maoh et al., (2009) developed an application of IMPACT (integrated model for population ageing consequences on transportation), a GIS-based model capable of assessing the ramifications of demographic changes, including population ageing, on the performance and usage of urban transportation systems. Unlike existing operational models, IMPACT possesses unique and novel features that enable it to model demographic changes and urban travel demand
for various age cohorts. The development of IMPACT follows the modular approach. The result is a versatile, stand-alone GIS-T model with an extensive set of policy handles that can be used to simulate scenarios relating to changes in (1) vital statistics (fertility, mortality, and migration rates), (2) land use characteristics per TAZ, including employment, new residential development, dwelling rent values, availability of schools, parks, recreational facilities, and the existence of commercial and industrial land uses, and (3) transportation infrastructure such as the enhancement of the level of service for existing road infrastructure or building new roads. Furthermore, the system can be used to simulate scenarios that pertain to changes in the socio-economic characteristics (e.g. people with driving licenses, car ownership levels, employment status, and household structure) of the driving population in the city.

### 7.6.7 A GIS-based approach for the screening assessment of noise and vibration impacts from transit projects

Hamed and Effat (2007) presented a GIS-based tool for the assessment of airborne-noise and ground-borne vibration from public transit systems, and its application to an actual project. The tool was based on the US Federal Transit Administration’s (FTA) approach, and incorporates spatial information, satellite imaging, geo-statistical modeling, and software programming. They presented a methodology of using spatial modeling, Geographic Information System, Visual Basic modeling, and satellite images to assess the environmental impacts from transit projects. A case study was presented on the application of the model for assessing the air-borne noise and ground-borne vibration impact resulting from a LRT project in an urban center in the Middle East. Specifically, the assessment was used in a multi-criteria analysis to evaluate two alternative alignments for the rail tracks. The method fully automates the assessment process; allows the evaluation of a very large number of potential receptor points; and allows the presentation of the results in a graphical format.

### 7.6.8 Geographic Information Systems (GIS) Based Model of Dairy Manure Transportation and Application with Environmental Quality Consideration

Paudel et al, (2009) used the survey information to develop a minimum cost spatial dairy manure transportation model where environmental quality and crop nutrient requirements were treated as
constraints. The GIS model incorporated land use types, exact locations of dairy farms and farmlands, road networks, and distances from each dairy farm to receiving farmlands to identify dairy manure transportation routes that minimized costs relative to environmental and other constraints. Analyses indicated that the characteristics of dairy manure, its bulk and relatively low primary N\textsubscript{2}, P\textsubscript{2}O\textsubscript{5} and K\textsubscript{2}O nutrient levels limit the distribution areas or distances between the farms and the land over which the manure can be economically spread. Physical properties of the land limit the quantities of nutrients that can be applied because of excess nutrient buildup in soil and potential to harm nearby water bodies and downstream people and places. Longer distances between dairy and farmland favor the use of commercial fertilizers due to the high cost of manure transportation. The GIS-based model made it possible to determine a least-cost dairy manure application distance for Louisiana’s major dairy production area. An optimal transportation route identified is a real world path with minimum cumulative impedance between the dairy farm origin and farm and pasture land destination using the existing road network. The analysis identified the shortest and cheapest existing road network by calculating and cumulating the contributions of all cost elements involved in the loading and transportation of manure from its origin to the point of final destination including the farm application cost.

7.6.9 A GIS-Based Environmental Modeling System for Transportation Planners

Brown and Affum (2002) developed a GIS-based environmental modeling system, termed TRAEMS, for use by transport planners in assessing the environmental effects of road traffic plans. The system utilises capabilities of GIS to integrate the output from a transport planning activity with land use information to model the environmental impacts of different road traffic scenarios. TRAEMS enables planners to test transport related environmental impacts at the same time as they are testing the traffic carrying efficiencies of network plans. TRAEMS operates entirely within the MapInfo environment, as an additional item in the MapInfo main menu, in the form of pull down menu. It is user-friendly, simple to use and requires no prior knowledge of MapInfo. All input data and output are maintained in MapInfo format, keeping everything simple and uniform. The various components are designed as individual programs in modular form, linked together through a common controller. Separate sub-modules have been designed
for each of the environmental factors of interest, namely: traffic noise, air pollution, energy consumption and storm water pollution. Through the identification of total pollutant load, and the location of this load in the network, the model has the potential to allow transport and land use planners to examine environmental consequences, not just transport consequences of proposals.

7.7 Software Available for GIS-T

There are many generic or multipurpose GIS packages, which can be used for GIS-T. Idrisi is a low cost, raster-oriented package with some vector analysis capabilities suitable for GIS-T applications, including the ability to calculate minimum cost paths, Eastman (1995). ESRI has been gradually increasing the functionality of its low-end ArcView software as it has released newer versions. ArcView Version 3.0 introduced an extension called Network Analyst who has a variety of automated routing functions, ESRI (1996). Among the high-end commercial packages are Intergraph’s Microstation, GeoMedia and ESRI’s ARC/INFO system, both of which have full network analysis functionality, Rodcay (1995). The other main generic software available are (CSDMS, 2000): AutoCAD Map software which is based upon AutoCAD Release 14; MapInfo which is a comprehensive desktop mapping software with a powerful graphical display program; ILWIS which uses an object-oriented approach in which maps, such as point, segment, polygon and raster maps are data objects; TNTmips which is MicroImages flagship product for geospatial analysis; GRAM++ which has been developed by CSRE IIT Bombay and which includes modules for import/export of different format data, map editing, raster analysis, vector analysis, network analysis etc. (Venkatachalam et al, 2001). But, among all these, probably the best known specialised GIS-T software package is Caliper Corporation’s TransCAD, a superset of their GIS Plus system. It includes all the standard GIS-T operations discussed above. Caliper also produces the in-expensive Maptitude desktop GIS package, which has extensive GIS-T functionality.

7.7.1 TransCAD

TransCAD is the first and only Geographic Information System (GIS) designed for use by transportation professionals to store, display, manage, and analyze transportation data.
TransCAD combines GIS and transportation modeling capabilities in a single integrated platform, providing capabilities that are unmatched. TransCAD can be used for all modes of transportation, at any scale or level of detail. With TransCAD, you can create high-quality map output using many of thematic mapping styles and options, unlimited colors, and fully-scalable line styles and true type map symbols. With a few clicks of the mouse, automatic mapping technology helps to create color and pattern coded maps, dot-density maps, scaled-symbol maps, and maps with integrated pie charts and bar charts. TransCAD also provides specialized mapping functions for transportation applications:

TransCAD is a state-of-the-art GIS that can be used to create and customize maps, build and maintain geographic data sets, and perform many different types of spatial analysis. TransCAD includes sophisticated GIS features such as polygon overlay, buffering, and geocoding, and has an open system architecture that supports data sharing on local and wide-area networks. TransCAD is the only software package that fully integrates GIS with demand modeling and logistics Functionality. The various advantages in TransCAD are:-

- GIS makes it possible for models to be much more accurate. Network distances and travel times are based on the actual shape of the road network and a correct representation of highway interchanges. Also, with networks we can specify complex road attributes such as truck exclusions, delays at intersections, one-way streets, and construction zones.
- The entire modeling process is more efficient. Data preparation is greatly facilitated and the database and visualization capabilities catch errors before they cause problems.
- The third advantage is the GIS itself. In TransCAD, different modeling equations can easily be derived and applied for different geographic sub areas. Similarly, TransCAD brings new and much-needed capabilities for measuring geographic accessibility.
- Lastly, the GIS approach provides a graphical solution that is easily understood. Users can convey highly technical information to the non-practitioner in a very straightforward and understandable manner.
7.7.2 MapInfo

MapInfo provides location intelligence solutions through combining software, data (both spatial and non spatial) and consultancy with project management, systems design and development, training and support. MapInfo produces a wide range of software including Spatial Cartridges for databases (Spatial Ware), Routing, Geocoding (Mapmaker), Site Analysis, Risk Analysis, Market Analysis, and the Envies web services suite along with the more traditional Geographic Information System (GIS) software.

7.8 Future Developments

7.8.1 Use of Expert Systems (ES) and Other Techniques
In the near future GIS-T is likely to benefit from an infusion of techniques related to ES. Heikkila et al (1990) suggest that ES can be used to determine which infrastructure improvements are appropriate in the light of changes within the GIS-T. The GIS-T can then be used to evaluate the effects of the infrastructure change and this information can be entered into the ES. Taylor (1990) has developed design criteria for knowledge based route guidance advisors which take into account not only the characteristics of the system but also the characteristics of the users to whom the advice is targeted. Spring and Hummer (1994), have demonstrated the use of engineering knowledge regarding accident causation to identify hazardous locations. Panchanathan and Faghri (1994), discussed the development of a knowledge-based geographic information system for managing and analyzing safety-related information for rail-highway grade crossings. Besides this, in future, there will be an increased use of advance techniques like Genetic Algorithm (GA), Simulated Annealing (SA), Decision Support Systems (DSS) etc. or some customized software, with GIS-T to get optimal solutions or to solve specific problems which are at present cannot be solved with present GIS-T tools.

7.8.2 Internet GIS-T
In future, data and maps and software will all be available on the internet for downloading or simply viewing, Maguire et al (1993). Many organisations are already making extensive use of
the internet and this is particularly true of municipal transportation departments which frequently make traffic service maps available over the map. Peng and Huang (2000) have done such a study to develop a web-based transit information system. Bertazzon and Waters (1996) have built a web site, which incorporates GIS functionality for determining shortest paths and provide route guidance and weather information on the web in real time.

### 7.8.3 Intelligent Transportation Systems (ITS) and GIS-T

As we all will agree, Intelligent Transportation Systems (ITS) is the future of transportation and there is bound to be an increase in the research in this key area, which is mainly the integration of GIS-T with GPS technologies. Two main components in this area are Intelligent Vehicle Highway Systems (IVHS), and Automatic Vehicle Location Systems (AVLS).

IVHS is a generic term for a number of GIS-T related applications, Johns (1990), including: automatic vehicle identification and billing (AVI); weighing in motion; collision warning and guidance; driver information and route guidance through advanced travel orientation systems (ATOS); advanced trip planning systems (ATPS); advanced travel conditions systems (ATCS); advanced traffic signal control and operation; automatic incident detection; and automobile vehicle spacing among a number of others. Goodwin (1994) notes that ORNL in the USA is developing an information infrastructure to support data sharing across all IVHS applications and uses.

AVLS systems are designed to locate vehicles at all times. Klesh (1989) noted that there are as many categories of AVLS as there are modes of travel. Concentrating on road vehicle applications AVLS were divided into two distinct categories: dispatch and stand-alone systems. The latter, often known as AVNS, are in-vehicle systems which are used to determine the shortest route between the vehicle’s present location and an intended destination, and have been discussed in detail by Jeffrey (1987) and White (1991). Klesh notes that the dispatch category (AVDS or AVMS) supports variety of applications in the private sector (e.g. application for taxicab companies, delivery and collection, services, and security agencies) and in the public
sector (e.g. police, fire department, ambulance, transit services). AVDS may employ GPS, a beacon, or some other technology to fix the vehicle’s position, but in addition this information is relayed to a central site from which additional resources may be dispatched, if and when necessary. Holland (1990) provides a detailed review of the use of AVLS technology in many urban transit systems and notes how it can be integrated with scheduling programs developed for transit operations. The next chapter will discuss ITS in much greater detail.

7.8.4 Temporal GIS-T

The construction of temporal GIS databases is one of the ongoing challenges for the GIS community. Such formulations are particularly useful in the transportation sector. A series of recent papers (Clark et al, 1996; Crawford-Tilley et al, 1996; Masuoka et al, 1996) discuss the design of a temporal GIS-T for the Baltimore-Washington region.

The Flow Chart in Figure - 7.5 summarizes the application of GIS trends.
GIS-T applications

Prevailing trends

- Service area analysis; O’Sullivan et.al(2000).
- Pavement management system; Simkowitz(1990).
- Transportation hazard analysis and incident management; Lepofsky et.al(1993).
- Evaluation of assignment techniques; Rao(2000).
- Transportation data sharing; Dueker & Butler(2000), Sutton & Wyman(2000).
- Network matching procedures; Xiong(2000).
- Freight transportation planning; Southworth & Peterson(2000).
- Human activity travel pattern studies; Kwan(2000).
- Traffic congestion studies; Taylor et.al(2000).
- Pollution emission assessment systems; Bachman et.al(2000).
- Transit information systems; Kharola & Gopalkrishna(1999).
- Accident analysis; Bydler & Nilsson(1977).
- Pedestrian accessibility studies; Aultman et.al(1997).
- Transportation improvement site selection.
- Land use planning.

Future developments

- Knowledge based GIS
- Web based GIS
- GIS coupled with customized software or advanced optimization technique.
- Integration of GIS and GPS for Intelligent Transportation Systems (ITS).
- Integrated urban transport / land use transport planning
- Facility location planning.
- Real time traveler information systems.
- Cargo fleet management & routing.
- Temporal GIS

Figure – 7.5: GIS-T Review
References:


**Exercises**

1. Explain the structure of GIS in Transportation.
2. What are the essential capabilities of GIS in transportation?
3. Explain how Shortest Path (SP) analysis is performed in GIS.
4. Write a brief note on matrix operations in GIS.
5. Categorize the applications of GIS in different fields of transportation.

**Assignment**

1. Perform the conventional Travel demand modeling procedure (preferably using tutorials or example given in software) using TransCAD or any other GIS software.