CHAPTER - 7

TRANSPORTATION NETWORK MANAGEMENT AND OPERATIONS
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7.0 GENERAL
A modern society can be viewed, in part as a system of networks for transportation, communication and distribution of energy, goods, and services. The complex structure and cost of these sub systems demand that existing facilities be rationally designed. Network analysis techniques can be of great value in the design, improvement, and rationalization of complex large scale systems.

The origins of network analysis are old and diverse. Network analysis relies heavily on graph theory, a branch of mathematics that evolved with Leonhard Euler’s formulation and solution of the famous Konigsberg bridge problem in 1936. The emphasis of research in 1950s and early 1960s was on formulation of new models and formulations of new algorithms. Later, emphasis shifted to the extension, computer implementation and analysis of previously designed models and algorithms. Network models and analysis are widely used in transportation system (Phillips, 1980.)

Transportation network is deemed to represent the supply side of the transportation system to satisfy the movement needs of trip makers i.e. road users in the study area. The transportation network management process includes variety of activities which includes planning, design, construction, operation, maintenance and related research and development. The activities needs frequent decision making to overcome various types of problems. The problems are not well defined and non-structured. The complexity of managing the network is further increased due to multiplicity of modes—road, rail, water, air and multiplicity of organization involved at the national, state and local levels. The authorities involved have different jurisdiction and need different sets of information with details, extent and scale. According to Cover et al (1994), the most challenging issues arises not from managing facilities or traffic but predicting and managing interaction between facilities and its use and among facilities.
The transportation network which involves 3.3 million km length of road network, 66000 km route length of rail, 116 airports having large kilometerage of airways and having large water front with very wide web of ‘waterways’ network make complex network.

The present study concentrates on road users’ movement in context of regional scale, hence road network management and operation problems of Anand District have been discussed.

The road network management problem faced by country is becoming complex. In the total road network of nation, the problems are of inadequate capacity, immediate repairs, operation, management and addition of new links at crucial locations. The services and performance levels of existing road in the country lag far behind the advancement in motor vehicle technology. The maintenance cost of existing road structure is rising, which is serious concern for the authorities responsible for their upkeep under tight budgetary constraints. The road users’ movement and safety on these roads is complex problem. To understand this, the network database created in GIS environment, makes integrated highway information system for various network management purpose including safety and efficiency of passenger and fright/goods movement.

GIS database brings information related to networks spatial spread, capacity, inventories, quality and traffic attributes like traffic volume, speed and crash events history. The description of a transport network in a computer model can be undertaken at different levels of details and requires the specification of its structure, its properties or attributes and the relationship between those properties and traffic flows. (Ortuzar and willumsen 1996). The elements of the network data model are divided in to two main themes or groups [Lubomir and Boris, 2006]

(i) Elements, spatially related to the transportation network. The set of element in these groups are shown in the Fig 7.1 below has network dataset, additional can be added to this data set.
(ii) Elements, logically related to transportation network. The set of elements in this group is presented in Fig. 7.2 the additional transportation assets can be added to this set.

Source: Lubomir and Boris (2006)

FIG 7.1 NETWORK DATA MODEL SET ELEMENTS.

Source: Lubomir and Boris (2006)

FIG. 7.2 ADDITIONAL ELEMENTS OF THE NETWORK DATA MODEL
7.1 NETWORK TERMS AND CONCEPTS
A network is defined as a set of nodes and links. Nodes are locations where flow
starts, end or branch. Links are conduits that carry flow from node to node. Every node
and link in a network has ID and, optionally, any number of attributes.

The notation of describing a network is \((N, A)\), where \(N\) is set of nodes and \(A\) is
set of arcs or links. As an illustration, the network in Fig.7.3 described as:

\[
N = \{1, 2, 3, 4, 5\}
\]
\[
A = \{(1, 2), (1, 3), (2, 3), (3, 4), (3, 5), (4, 2), (4, 5)\}
\]

Example of \((N, A)\) network,

![Network Diagram](image)

**FIG.7.3 LINK NODE REPRESENTATION OF NETWORK \((N, A)\)**

The road network in the study region is digitized as line layer. The line layer is used to
create GIS network structure for SH roads. Fig 7.4 shows node link details of SH in
Anand district

7.2 LINK DATA REQUIREMENTS
For use with a conventional assignment programme, basic minimum network data
consists of initial and final node (origin and destination nodes), measure of cost of travel
on each link, link length, link type—which conveys information about width or number of
lanes, speed-flow relationship and DSV or capacity, and exit type incase of urban
transportation network (final node, eg. Give way, roundabout, junction type and
capacity). The examples of network link level data have been provided in Table 6.14
Annexure VI.
Networks are used to analyze the way people and goods flow from one location to another. The information contained in and derived from network is critical for application in routing and scheduling, mode choice modeling and traffic assignment models. A network is a mathematical graph that is abstract representation of the transportation system. The application of network analysis techniques often requires not only “where you want to go” but also “which way you ought to go”.

Modeling for simultaneous selection of optimal Bus Route and their frequencies for Ahmedabad, Umarigar, (1982) has developed method such that the selection of the routes and the assignment of frequencies is done simultaneously for the bus transit system. The method has been developed in four stages: (i) to generate a trip distribution matrix (ii) to concentrate the flow of passengers on the road network such that the sum of passenger-riding-time-cost and operation cost is minimized, (iii) to generate a large set of all possible route that satisfy the various constraints, (iv) to select route and their frequencies so that number of transfers saved on the network is maximized. Heuristics
have been used for the concentration of the flow and generation of the routes while Linear Programming (LP) has been used to select route and their frequencies.

A method has been suggested to estimate trip distribution matrix by using generally available traffic data of the existing routes for the city bus network.

The flow of passenger on the various link of the network is concentrated such that the sum of passenger-riding-time-cost and operation cost of the vehicle is minimized. An heuristic algorithm has been developed for concentrating the flow. The relationship between the number of bus trips and the flow of passenger on a link has also been derived. The starting network consists of all the links where vehicles could possibly travel. Passenger flows have been systematically concentrated by eliminating the links, in stage such that the total cost is minimized.

For a given desired travel matrix, a large set of all possible routes between O-D pair is generated using the heuristic procedure. The generated routes satisfy the practical constraints of the length and the deviation from the shortest path.

The total number of transfers saved on a route is determined based on the size of the turning movements along the route and the estimated number of bus trips on the links. For a given operating fleet size the simultaneous selection of routes and their frequencies is done by Linear Programming such that the total number of transfers saved on the network is maximized.

7.3 CAPACITY OF LINKS IN ROAD NETWORK

Capacity of road link is defined as maximum hourly volume (vehicle/hour) at which vehicles can reasonably be expected to traverse a point or uniform section of a lane or roadway during a given time period under the prevailing roadway, traffic and control conditions. Design service volume is the maximum hourly volume at which vehicles can reasonably be expected to traverse a point or uniform section of a lane or roadway during a given time period under the prevailing roadway, traffic and control conditions while maintaining a designated Level of Service (LOS) (IRC:64-1990).

From the view point of the smooth traffic flow, the width of pavement is not designed for capacity which is at LOS E, but designed for LOS B which provides stable flow zone, reasonable freedom to drivers in terms of speed selection and manoeuvers.
with in traffic stream. The design service volume is 0.5 times capacity. The recommended design service volume for various types of roads in plain terrain is given in Table 7.1.

### TABLE 7.1 RECOMMENDED DESIGN SERVICE VOLUME FOR VARIOUS TYPES OF ROADS IN PLAIN TERRAIN

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Road category</th>
<th>Curvature degree/km</th>
<th>Suggested DSV PCU/ day</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Single lane roads</td>
<td>Low (0-50)</td>
<td>2000</td>
</tr>
<tr>
<td></td>
<td></td>
<td>High (above51)</td>
<td>1900</td>
</tr>
<tr>
<td>2</td>
<td>Intermediate roads</td>
<td>Pavement width about 5.5m and good stable shoulders on either side</td>
<td>Low (0-50)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>High (above51)</td>
<td>5500</td>
</tr>
<tr>
<td>3</td>
<td>Two lane roads carriage way 7.0m good shoulder</td>
<td>Low (0-50)</td>
<td>15000</td>
</tr>
<tr>
<td></td>
<td></td>
<td>High (above51)</td>
<td>12000</td>
</tr>
<tr>
<td>4</td>
<td>Multi lane roads: Four lane divided carriage way, good earthed shoulders, 3.0m central verge. Four lanes divided with 1.5m good shoulders on either side.</td>
<td>Low (0-50)</td>
<td>35000</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Low (above51)</td>
<td>45000</td>
</tr>
</tbody>
</table>

Source: IRC: 64-1990

Capacity of various links on the roads of study region is evaluated based on above standards and documented and presented in Fig.7.5.

### 7.4 GIS IN ROAD NETWORK MANAGEMENT: ADVANTAGES.

GIS, adds a degree of intelligences and automation to a transportation database, is a powerful tool in the analysis and design of road network related problems. For a road network link which is georeferenced and Linear Referencing Method is applied for database is populated the GIS knows location of kilometer stones, physical intersections, traffic signs, cross drainage works, pavement conditions and capacity of stretch. Due to this, the capability of analysis in GIS is considerably enhanced. Topology permits various queries to be performed and encourages new type of analysis.

Normal practice, however, is to model the network as a directed graph, i.e. a system of nodes and links joining them (see Larson and Odoni 1081, ) most nodes are taken to represent junctions; links are characterized by several attributes such as length, speed, number of lanes, capacity and so on. A centroid is a location within zone where trips are considered to begin and end.
SAFE AND EFFICIENT REGIONAL ROAD USERS' MOVEMENT FOR GUJARAT STATE IN GIS ENVIRONMENT

FIG 7.5 LINK LEVEL DATA FOR SH IN ANAND DISTRICT
7.5 GIS BASED NETWORK MANAGEMENT STUDIES

City of El Paso, Texas, and its sister city, Juarez, Mexico, constitute the largest metropolitan area on the border of the United States and Mexico. Maintaining existing roads and building new ones are challenges for any growing municipality. Without coordinated digital tools for planning, scheduling, and performing work, documenting service requests and work orders and status reporting are real challenges. El Paso decided to meet these challenges by implementing a Traffic Management Information System (TMIS) on GIS city wide, so that it could be accessible by all departments ESRI (2005).

In the first step they have used city work assets and work order database an ArcSDE which helped to process 400 service requests and 1500 work orders in the first month. In phase two, collected pavement and asset inventory information along 588 miles of existing roadway and 60 miles of new roadway. The asset information was captured by a mapping van equipped with an inertial GPS and four positionally mounted digital cameras. The end product was highly accurate Linear Referencing System (LRS), a collection of road right of way assets, and pavement condition index ratings, all of which are stored in the ArcSDE geodatabase. In phase three, added enriched work order and pavement management functions and GIS data to TMIS helped to better plan and budget preventive pavement maintenance, saved time by eliminating data entry duplication. It has also permitted better tracking of labour, equipment and material usage cost allowing the street department to justify the additional funding needed to maintain the city streets.

Real World transportation networks have characteristics that are unique relative to the most of the universe of the possible networks. Transportation networks are sparsely connected. Each node of is directly connected to only a tiny portion of the other nodes in the network (Van Vliet 1978).

Charles Barnwell (2005) build an integrated transportation network called ITS Roadnet in order to meet the transportation GIS data needs of a variety of a stakeholders groups including planning and Public works, Traffic Engineering, Public safety, Transit and other business units at the Municipality of Anchorage (MOA) in state Alaska. The street centerlines maintained by MOA in Arc Info coverages are taken as reference network. These are re-engineered in geodatabase model as a geometric network.
SAFE AND EFFICIENT REGIONAL ROAD USERS’ MOVEMENT FOR GUJARAT STATE IN GIS ENVIRONMENT

comprised of edges and junctions (nodes). A geometric network representation was selected in order to support routing, modeling and navigation function specified by stakeholders. Thus, the edges and junctions contain network impedances and connectivity between the network features. The transportation inventory data such as pavement, culverts, bridges, accidents, traffic volumes, bus stops etc. are managed as point or linear events. This allows a more flexible way of accurately locating the extent of each feature by means of linear referencing. A Roadnet route system was developed based on street name, which resulted in more than 4800 routes. In addition other routes were created as transit routes. These routes provide the linear measures for the events. The event can be referenced to the route by three methods: by mile point (to and form), by address range which is carried in the geodatabase or by lat/lon coordinate. The ITS Roadnet Geodatabase successfully meets the goals of the ITS programme in providing integrated environment using current technology such as ArcGIS 9.x linear referencing.

Pawar et al (2000) have developed a GIS based information system for roads. It was a project undertaken for Mouda taluka of Nagpur District for Public Work Department. The objective was to harness the utilities provided by GIS technology to manage existing transportation resources and enhance the efficiency of transportation network. The kilometerwise transportation related spatial and non-spatial data were collected for this purpose. Data on road number, road condition, carriageway width, pavement type, speed limits, drainage structures, rain fall were the attributes for the study. It has been concluded that the system would be extended to entire state and future goals would be more of management and analysis oriented. The long term goals would include publishing the Road Information System (RIS) on internet and intranet. This work was expected to help in building the Linear Referencing System (LRS) for highways and other road system.

7.6 PAVEMENT MANAGEMENT IN IMPROVING SAFETY AND EFFICIENCY

Jenelius et al (2006) studied vulnerability analysis of road network of northern Sweden (Norrland plus the county of Dalarna) and results are presented in GIS. They defined vulnerability (a susceptibility for rare, big risk), reliability (the degree of certainty with which a traveler is able to estimate his own travel time) and risk (probable cost of
harmful event) for road network of northern Sweden. The pavement evaluation study for riding quality and structural strength was carried out on SH 26 between Bandhani Intersection and Valetva intersection. The Benkelman Beam design Method for overlay design rebound deflections measured at 50 m interval. The Bump Integrator was used to find roughness index for the stretch. The overlay design thickness results are presented in Table 7.2. The visual display of results with overlay thickness is given in Fig.7.6.

**TABLE 7.2 FLEXIBLE OVERLAY DESIGN AND RIDING QUALITY DATA**

<table>
<thead>
<tr>
<th>Chainage, Km</th>
<th>Characteristic Deflection Dc (mm)</th>
<th>Overlay in terms of BM (mm)</th>
<th>Overlay Provided DBM (mm)</th>
<th>BC (mm)</th>
<th>Total Overlay Thickness (mm)</th>
<th>Riding Quality</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-1</td>
<td>1.825</td>
<td>176</td>
<td>80</td>
<td>60</td>
<td>140</td>
<td>The riding quality is good after improvement compared to before</td>
</tr>
<tr>
<td>1-2</td>
<td>2.766</td>
<td>221</td>
<td>95</td>
<td>60</td>
<td>145</td>
<td></td>
</tr>
<tr>
<td>2-3</td>
<td>2.315</td>
<td>194</td>
<td>80</td>
<td>60</td>
<td>140</td>
<td></td>
</tr>
<tr>
<td>3-4</td>
<td>1.935</td>
<td>184</td>
<td>80</td>
<td>60</td>
<td>140</td>
<td></td>
</tr>
<tr>
<td>4-5</td>
<td>1.975</td>
<td>187</td>
<td>80</td>
<td>60</td>
<td>140</td>
<td></td>
</tr>
<tr>
<td>5-6</td>
<td>2.242</td>
<td>192</td>
<td>80</td>
<td>60</td>
<td>140</td>
<td></td>
</tr>
<tr>
<td>6-7</td>
<td>1.902</td>
<td>181</td>
<td>80</td>
<td>60</td>
<td>140</td>
<td></td>
</tr>
<tr>
<td>7-8</td>
<td>2.019</td>
<td>187</td>
<td>80</td>
<td>60</td>
<td>140</td>
<td></td>
</tr>
<tr>
<td>8-9</td>
<td>1.475</td>
<td>152</td>
<td>70</td>
<td>40</td>
<td>110</td>
<td></td>
</tr>
<tr>
<td>9-10</td>
<td>1.518</td>
<td>152</td>
<td>70</td>
<td>40</td>
<td>110</td>
<td></td>
</tr>
</tbody>
</table>


The road surfacing work was carried out in early 2006, by PWD. To get improvement in traffic characteristic: speed the traffic volume and spot speed survey was done. The results are presented in Table 7.3. The results show significant improvement in the spot speed at the site. The change in average traffic stream speed is about 12%.

### 7.7 INVENTORY MANAGEMENT

The Intermodal Surface Transport Efficiency Act 1990 (ISTEA-1990) requires traffic monitoring and system management monitoring of pavements, bridges, safety, congestion, public transport facilities and intermodal facilities. These systems call for co-oriented efforts to collect, manage, analyze and store transportation related data.

Harter, et al (2008) developed GIS-T system for evaluation of LOS, Road Improvement, and cost calculation and the system was validates by applying to estimate improvement and costs developed for the 2020 Panama City Long Range Plan completed...
FIG 7.6 OVERLAY THICKNESS DATA WITH STRIPS CHARTS
in 1996. The system integration was done using Arc View GIS and Visual Basic plus MS Access database.

Miller et al (1999) studied time critical logistic problem using Salt Lake City Network and congestion pattern is evaluated with 20 minute time interval of traffic flow using Dynamic Traffic Assignment (DTA) and results presented in Arc View GIS software.

GIS based Transportation Information Management System (TIMS) was developed by Santhakumar (2002) using Visual Basic 6.0 combined with Microsoft access to access information on highways around Tiruchirapalli (GIS/HAT).

Dijkstra's shortest path algorithm used to determine shortest path from one vertex to another based on distance/time and presented into different colours and width. Based on the speed data on the network, Average Daily Traffic (ADT) and width of the road, the volume/capacity (v/c) ratio is obtained and shown graphically on network map. The TIMS is cost effective and works better with a moderate system. The road network and related inventory collected, and coded to suitable format. The inventory collected includes location of intersections, bridges and kilometer stones. The inventory has been shown in the Fig.7.7. This becomes a good handy tool for highway engineers and decision makers.

7.8 CONCLUSIONS

Highway network represented using link-node model with attributes and inventory data is important decision support tool. The Benkelman beam design data based overlay design is presented using GIS-T. The improvement increases considerable speed making traffic operations and road users' movement efficient.
<table>
<thead>
<tr>
<th>Mode</th>
<th>CVC in May 2005</th>
<th>CVC in April 2006</th>
<th>% Change</th>
<th>Spot-speed in May 2005</th>
<th>Spot-speed in April 2006</th>
<th>% Change in V</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Number</td>
<td>Percentage</td>
<td>Number</td>
<td>Percentage</td>
<td>N</td>
<td>V</td>
</tr>
<tr>
<td>Two-wheeler</td>
<td>1587</td>
<td>42.90</td>
<td>1725</td>
<td>41.70</td>
<td>8.70</td>
<td>348</td>
</tr>
<tr>
<td>Auto rickshaw</td>
<td>455</td>
<td>12.30</td>
<td>531</td>
<td>12.84</td>
<td>16.70</td>
<td>87</td>
</tr>
<tr>
<td>Cars</td>
<td>616</td>
<td>16.65</td>
<td>695</td>
<td>16.80</td>
<td>12.82</td>
<td>170</td>
</tr>
<tr>
<td>Buses</td>
<td>148</td>
<td>4.00</td>
<td>185</td>
<td>4.47</td>
<td>25.00</td>
<td>59</td>
</tr>
<tr>
<td>Trucks</td>
<td>145</td>
<td>3.92</td>
<td>140</td>
<td>3.38</td>
<td>-3.45</td>
<td>65</td>
</tr>
<tr>
<td>LCVs</td>
<td>302</td>
<td>8.16</td>
<td>341</td>
<td>8.24</td>
<td>12.91</td>
<td>47</td>
</tr>
<tr>
<td>Chhakdo</td>
<td>291</td>
<td>7.87</td>
<td>329</td>
<td>7.95</td>
<td>13.06</td>
<td>105</td>
</tr>
<tr>
<td>Tractors</td>
<td>155</td>
<td>4.19</td>
<td>191</td>
<td>4.62</td>
<td>23.23</td>
<td>48</td>
</tr>
</tbody>
</table>

Average Change 11.93

N = Sample Size, V = Spot Speed, kmph  σ = Standard Deviation
FIG. 7.7 THE ROAD INVENTORY IN STUDY AREA