Planning and Evaluation of Rural Road Network Connectivity Using GIS

Anil Modinpuroju[1] and C. S. R. K. Prasad[2]

[1] Research Scholar, Dept. of Civil Engineering, National Institute of Technology Warangal, Warangal 506004, India. E-mail: anilmodin@yahoo.com
[2]Professor, Dept. of Civil Engineering, National Institute of Technology Warangal, Warangal 506004, India. E-mail: csrk@nitw.ac.in

Abstract: Rural Road Connectivity, and its sustained availability, is a key component of Rural Development. Rural roads are connecting areas of production with markets and connecting these with each other or to the State and National Highways. The unavailability of database is major constrain to the access of rural roads. This paper envisages consolidation of the existing Rural Road Network to improve its overall efficiency as a provider of transportation services for people, goods and services. This study has undertaken an extended attempt to develop Geographic Information System (GIS) based rural road database so that planners, decision makers, researchers and other different level authorities in the rural road sector will be benefited from the final output. The study area is located in Warangal District, Telangana, India. Network analysis has been conducted to select shortest path, service area accessibility, and closest facility, location allocation of a facility and shows the vehicle routing in terms of travel time, between two locations in the study area and towards Rural Hubs. The average travel times were observed from the field surveys. Rural Hubs has been selected, from 46 habitations found in the study area, based on the cumulative weightage of rural infrastructures and the number of trough-routes they have. Furthermore, an evaluation of road network has done based on the connectivity measures before and after identification of critical links of the network and also identifies the centroid point of the network by measuring the connectivity values of the nodes. The paper also focused on development of planning model for upgradation of rural roads based on the link weightage and pavement condition index (PCI) of the road.

INTRODUCTION

In India, rural roads shares more than 85% of the road network of the country. Hence keeping them in serviceable condition is crucial for the rural people get access to social facilities like health, education and market. However, the connectivity is not to

the desired level. In recent past, 2000, the Government of India initiated a nationwide program known as PMGSY, to provide connectivity to all the villages in a phased manner, so as to connect through all-weather roads to unconnected habitations. The volume of information is difficult to process, manage, update, sort and retrieve by traditional, manual methods due to the fact that handling, managing and updating of the data by the traditional methods is not only tedious and time consuming but also it is difficult to sort and retrieve. To obviate these difficulties it is, therefore, considered necessary to develop all the spatial and attribute data in digital format. Therefore, GIS is an essential tool to be placed on comprehending the information of spatial and non-spatial data over a space and time. "GIS is a computer-based tool which can handle the entire database and help in the management of the entire rural development program" (Durai et al. 2004). Rao et al. (2003) developed an information system for rural road network planning for Rupauli block of Purina District, Bihar, India. The optimum rural road network was developed and road maintenance management system helps in understanding the sustainability of existing roads for a longer time with minimal efforts. Mishra and Naresh (2009**)** developed a geo-based rural roads information system. They developed a spatial and non-spatial rural road database which can be viewed by common man to get the information from the map. Praveen et al. (2013) explained the use of network analysis, in determining the optimal route between two locations based on a specific travel expense. Based on the above research studies it is observed that, GIS can be used as an effective tool to prepare a Geo-spatial rural road information system which will be useful for rural road planning and development. Hence, in this paper, an attempt is made to prepare a rural road information system using GIS.

METHODOLOGY

In order to achieve the objectives, the proceeding steps to ensure the continuous and logical build-up of defining and justifying the study. Further, the detail description of the step by step procedures used is given below.

- Collection of data, in the form of map, for the study area from different sources.
- Gathering road attribute data which include the average travel time of each link from the field to develop a database.
- Collection of turn and travel direction restriction.
- Development of database of the road network by putting attributes variables.
- Preparation of turn table.
- Development of network dataset of the road network.
- Network Analysis was carried out for a study area.
- Performing connectivity analysis of a network.
- Develop a planning model for rural roads.

STUDY AREA AND DATA COLLECTION

Geesugonda mandal was selected as the study area, which was located in Warangal district of Telangana state. It was located between 17°55'00"and18°00'00" latitudes 79°45'00" and 79°50'00" E longitudes.

Status of Road Network

The study area has total 140.63Km of roads. The roads of the study area can be classified based on the surface type was shown in figure 1 and figure 2 shows the existing road network and connectivity status of the Mandal.

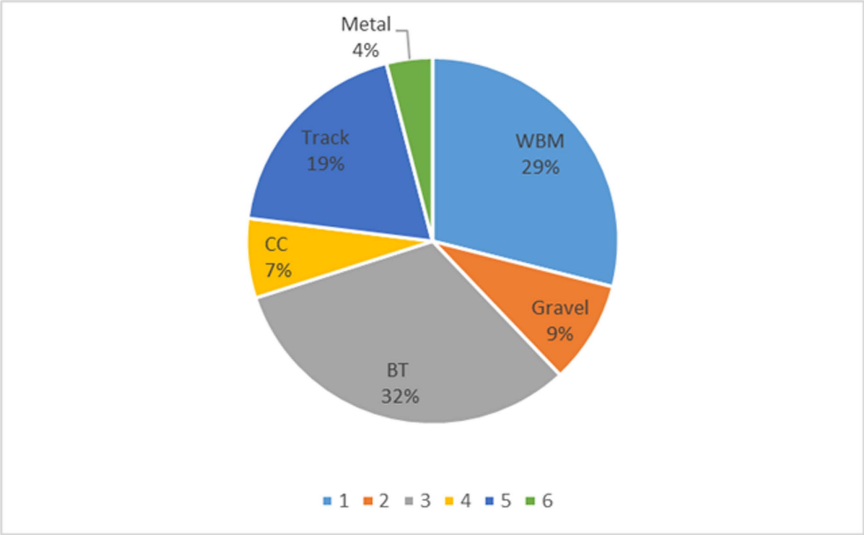

FIG. 1. Existing road network by surface type.

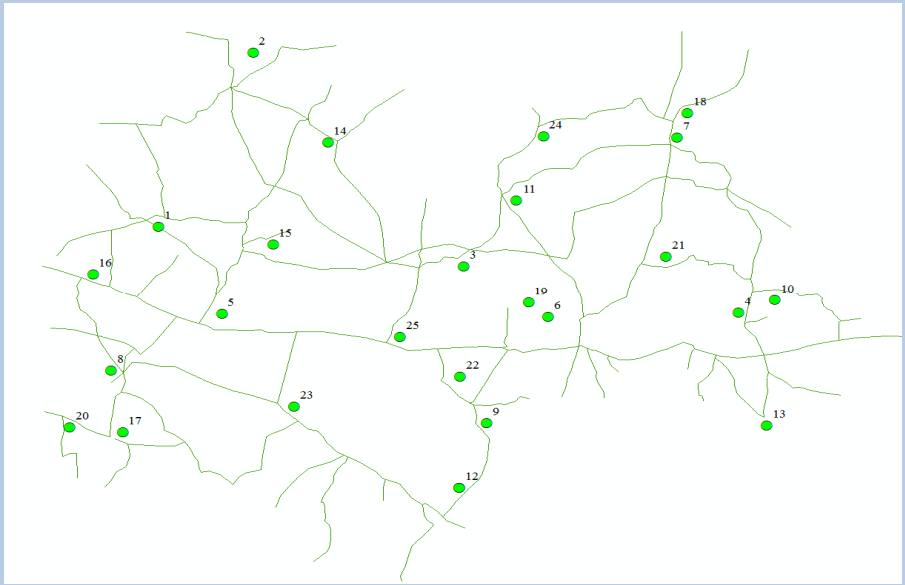

FIG. 2. Connectivity status of the study area.

Data Collection

Hand held GPS instrument was used for identification of facilities location, Pavement details and road inventory data were observed from the field surveys. Secondary data like SOI toposheet, habitation details as well as road information data were collected from Panchayathi Raj department of Warangal district.

NETWORK AND CONNECTIVITY ANALYSIS

Creation of Geo- Database

"A Geo data base is similar to a file which can be used to store, query and manage both spatial and non spatial data". But it has few advantages over it, like it provides support for advanced geometry. Also it supports user-defined relationships among feature classes. Geo database is created by using the spatial data and non spatial data using arc catalogue in GIS environment. Feature datasets are used to group the related features together. All the feature classes are created within the dataset. Within Feature dataset a feature classes can be created, it has an advantages to create Feature class within Feature dataset, like all Feature classes have a same coordinate system. Also it is possible to create Topology for each Feature class. Within Feature datasets it is possible to add new datasets like Feature class, Network datasets and Topologies.

Network Analysis

The most economic path or minimum fuel consumption path are the different shortest path problems in a network from one location to other. This study also focused on determining the optimal route between two or more location based on an average travel time. The travel times were observed from the field studies. The analysis was done by using the extension Network Analyst extension of Arc GIS software on the whole study area to locate some best routes. The Network Analyst gives the user the ability to produce a map and direction for the quickest route among several locations. The user can define the locations either manually or through a database with the approximate locations in respect to geographic coordinates – this database includes information such as the address and link name for each location. Dijkstra's Algorithm was used in network analyst's tool to solve the shortest path problems. The following figure 3 shows the results i.e., shortest path towards the Rural Hub in study area , figure 4 shows the service area accessibility for the time period of 5 minutes and 10 minutes from rural hub and figure 5 shows the location allocation for the educational facilities. The Rural Hubs were selected from the habitations on the basis of cumulative weightage and the number of trough-routes connected (source: PMGSY-II guide lines).

Connectivity Analysis

Identification of critical links

The critical links which were intrupt the traffic/vechicle flow throught the rainy season either bad condition of the pavement or flooding.The shortest path analysis was carried out before and after identification of critical links or any barrier structure in the network shown in figure 6. The critical links were identified from the field observations and opinion of field engineers.

Identification of a centroid point from the network

Connectivity analysis was carried out using shimbel distance/ shimbel index method. Shimbel distance is a topologic network analysis that is restricted to the shortest routes between nodes. The relative accessibility values of an each node were obtained from this method. The node which had less accessibility value was considered as a centroid

point of the network based on the connectivity. The village Arepalli having minimum accessibility was considered as a centroid point in the network.

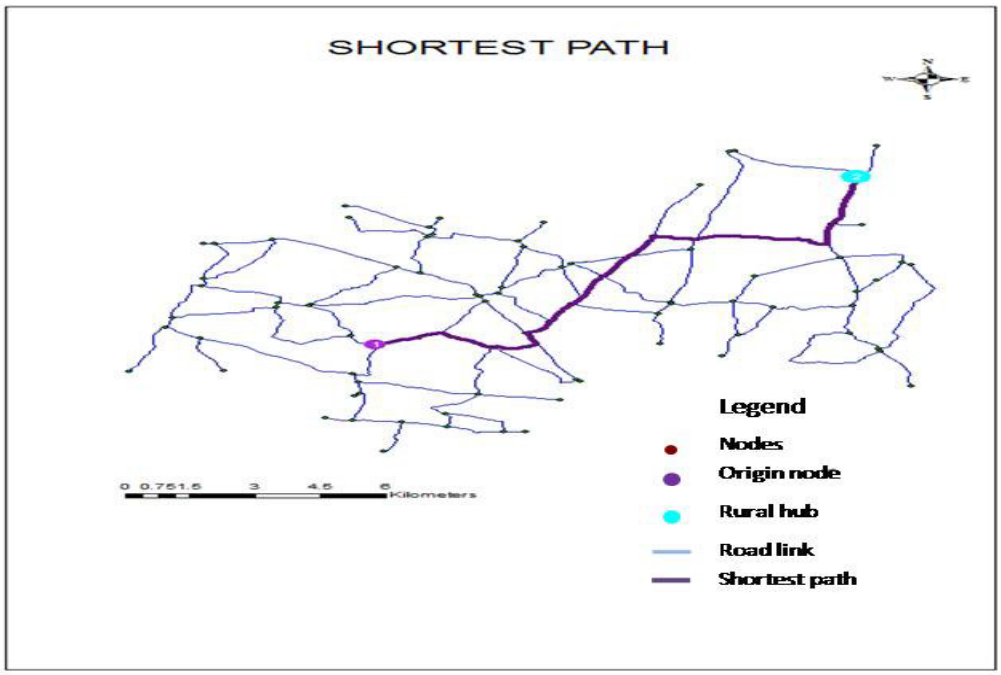

FIG. 3. Shortest path towards to Rural Hub from a habitation.

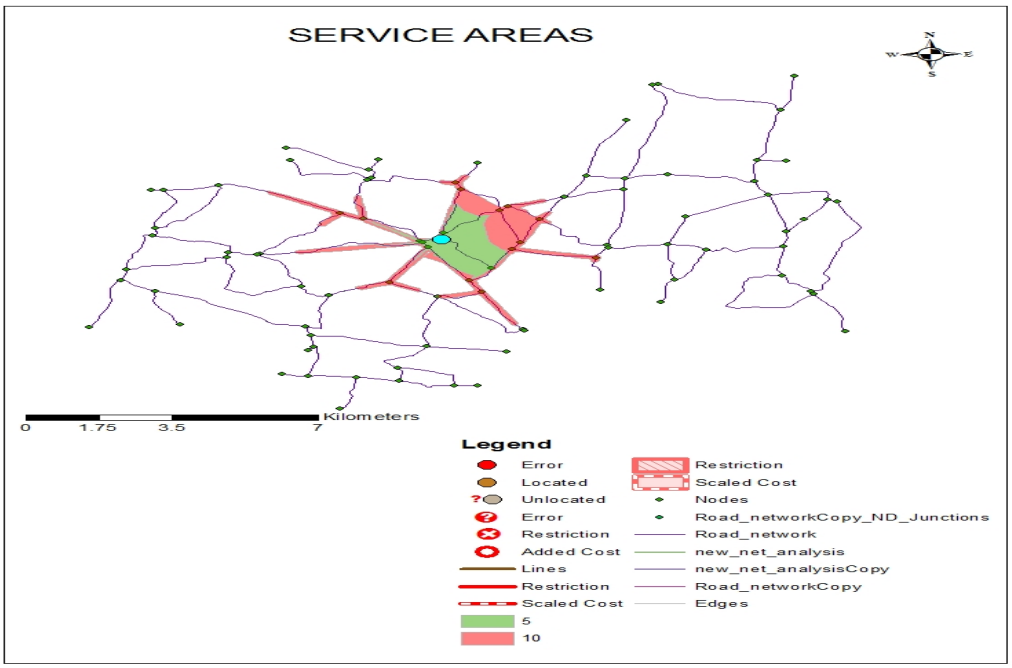

FIG. 4. Service Area accessibility from the rural hub.

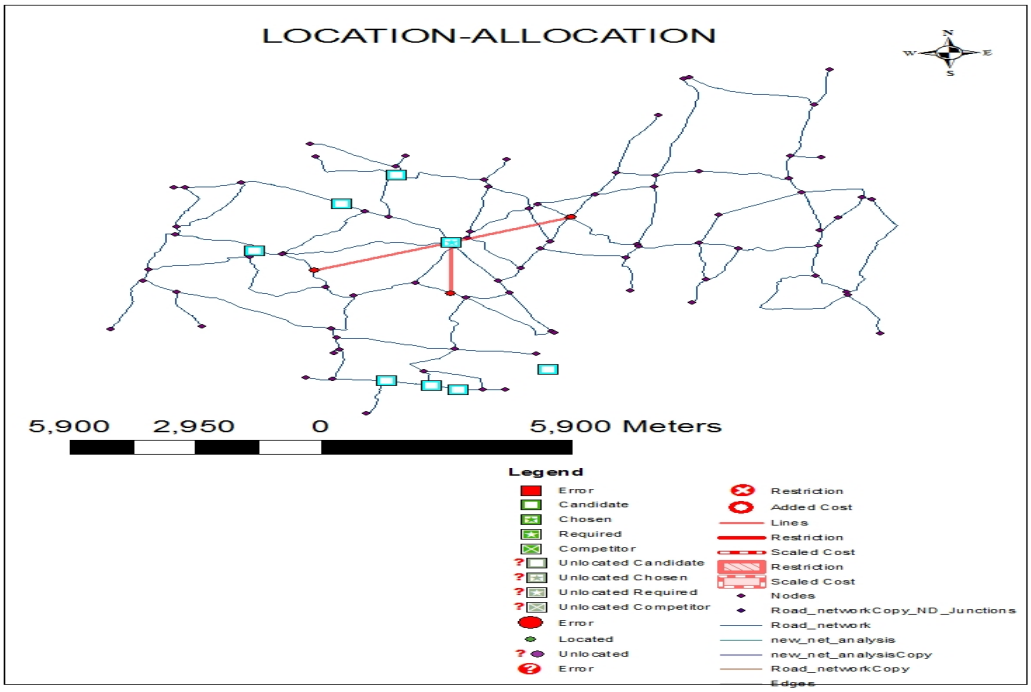

FIG. 5. Location –Allocation for the educational facility.

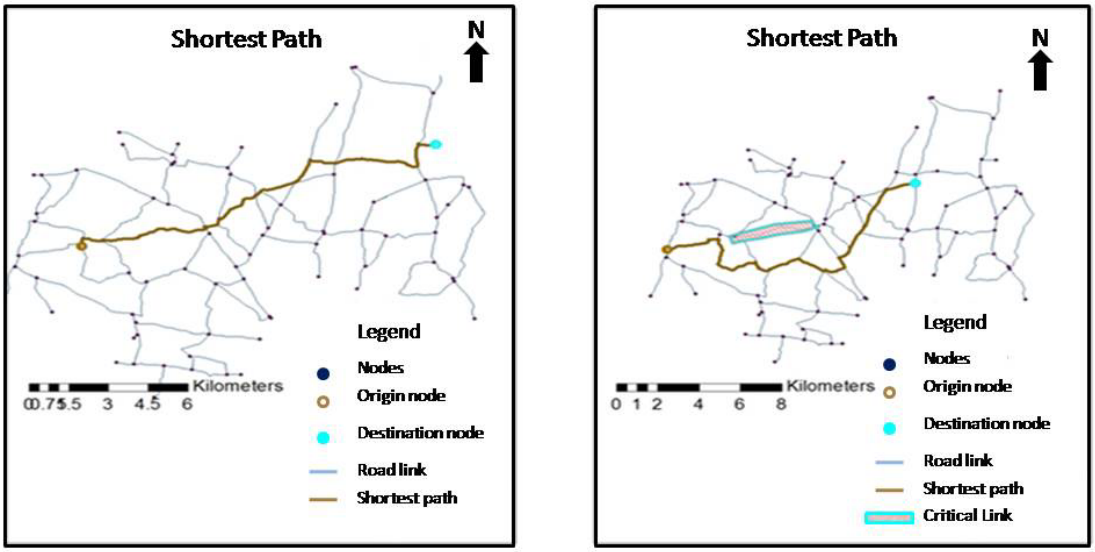

FIG. 6. Shortest route of a network before and after identification of a critical link.

MODEL DEVELOPMENT FOR RURAL ROADS

The exisisting rural road planning models in India were developed based on the interaction between the settlements and prioritisation of the roads. In the present study the Upgradation of the network was done by strengthening/Maintenance of the road

links. The strengthening of road link was based on the population benefited by the link, facility index of the villages and the Pavement Condition Index (PCI) of the road. In this study PCI value of each road link was determined based on the comfortable driving speed of the vehicle as per PMGSY-II guidelines and PCI values are indexed on scale from 1 to 5 where '1' shows worst possible condition and '5' shows the best possible condition of the pavement. The comfortable speed of the vehicle was observed from the field surveys by travelling on each road link. The car was used as a design vehicle. Facility index values were obtained from the facilities availability from the village. Further, the link weightage was estimated using the equation 1 given below.

$$W_{ij} = (P_i * P_j)(F_i - F_j) / d^2 \quad (1)$$

where,
W_{ij}- Weightage
P_i and P_j- Population of villages i and j
F_i and F_j – Facility index values of village i and j
d- Distance between village i and j
If $F_i - F_j = 0$ then take this value as 1

Strengthening or maintenance of Rural Roads

The link weigthtage and PCI value of the links are taken as a measure for strengthening/upgradation of the pavement based on the criteria is given below.

- First strengthening of the through rout based on which link had higher weightage and who's PCI value is < or = 2.
- After this strengthening of those link routes based on which link had higher weightage and who's PCI value is < or =2.

Prioritization of the road links for strengthening or maintenance works were prepared for the study area based on the model was shown in table 1.

Table 1. Priority List for the Maintenance of links

Node i	Node j	Weightage	Priority
23	46	55.67	1
22	9	14.42	2
18	22	12.9	3
1	12	3.44	4
20	26	3.37	5
25	33	2.54	6
30	7	2.12	7
6	32	1.72	8
14	26	1.71	9
1	23	1.53	10

CONCLUSIONS

This study has undertaken an extended attempt to develop Geographic Information System (GIS) based rural road database. The developed Advanced Rural Road Information System (ARRIS) will be useful to policy makers, government departments, Non-Government Organizations, general public for planning, development and management of road facilities in the rural areas. Geesukonda habitation was designed as a rural hub based on the cumulative weightage of rural infrastructures and the number of trough-routes they have. Network analysis was carried out for shortest path analysis, closest facilities to habitations, Vehicle routing problems, Location – Allocation problems. Connectivity analysis was carried out for the study area before and after identification of critical links of the network. GIS based rural road model has been developed for Strengthening of roads based on population benefited and PCI value of the link.

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