Innov. Infrastruct. Solut. (2016)1:41
DOI 10.1007/s41062-016-0041-8

SHORT COMMUNICATION

Facility-based planning methodology for rural roads using spatial techniques

Anil Modinpuroju[1] · C. S. R. K. Prasad[1] · Mukesh Chandra[1]

Received: 15 May 2016 / Accepted: 15 September 2016

Abstract Provision of good rural roads to meet the public facilities changes the characteristics of rural transport. This paper aims at identifying the roads in a network for upgradation and maintenance based on the pavement and develop a methodology for prioritization of the roads using village facility indices. The study area is located in Warangal District, Telangana, India. Spatial analysis was carried out in the study area to identify the maximum coverage distance of the facility to design the village facility index using ArcGIS software. A priority list of the road links to upgradation works is prepared by calculating the link weight using gravity formula. A Geographic Information System (GIS)-based rural road database is developed, which will help the authorities in the road sector to expand the infrastructure facilities for current and future requirement. Practical applications of the model exhibit significant advantages over the general practices of rural road planning in India.

Keywords Rural roads · Facility planning · Geographic information system · Spatial analysis

Introduction

Rural Roads play a vital role in the development of any emergent country. In India, rural roads share more than 85 % of the road network of the country. Hence maintenance that in serviceable condition is essential for the rural people to get access to public facilities. A well-planned road network in rural areas is one of the most important infrastructure elements which improves rural accessibility and contributes to the rural development as a whole. To improve the connectivity among villages and also toward the public facilities, there is an urgent need to improve the condition of existing roads by planning for upgradation. Proper planning and development of the rural road network, therefore, assumes its importance in terms of providing connectivity to the facilities.

In the past, different methodologies were developed for the rural road network planning. Sufficiency Rating methods were used in the early 1950s for planning maintenance and improvement of US Highways [1]. Makarachi and Tillotson [2] developed a settlement interaction-based model for planning in rural areas using gravity formulae. Ifzal and Ernesto [3] Poverty reduction requires the economic growth which is observed from providing good access to the public facilities like education, market centers, health services, and others by the accompanied macroeconomic management and good governance. Shrestha [4] developed two computer-aided models for planning and prioritizing district transportation networks by considering the economic net present value (ENPV), an economic internal rate of return (EIRR), and the benefit-cost ratio (B/C ratio). Singh [5] designed an accessibility index for rural road network planning in developed countries in GIS environment. Dhamaniya [6] developed a methodology for maintenance of rural roads by considering the utility value of habitation and PCI of the road. Shrestha and Benta [7] considered the parameters like Population served by links, Person-km, Population served/km, and Gravity flow model for prioritization of roads. In many models, the prioritization process is very complex, taking too many indicators for ranking road links, some of them

✉ Anil Modinpuroju
anilmodin@yahoo.com

[1] National Institute of Technology Warangal, Warangal, Telangana, India

possibly irrelevant. Kumar and Kumar [8] explained that, for prioritization of rural roads, generally two broad approaches are used: (a) sufficiency rating and (b) cost-benefit analysis. The main drawback of the sufficiency ratings is its randomness. In the cost-benefit analysis various costs and benefits associated with a road have to be evaluated in the same monetary terms, which is a difficult task. Accessibility to the rural population is considered a benefit of the investment in rural roads. Thus, the ratio of population served by a link and its construction cost can be taken as a good proxy for the expected benefit from a rural road link. The link serving higher population per unit investment receives high priority. Typically, rural roads are constructed to connect the rural settlements, thus improving accessibility. Therefore, road access to the settlements may be the most significant indicator.

The papers mainly focused on the development of criteria for the prioritization of links for upgradation in a network by estimating the link weight using facility indices. The planning methodology for a model is developed in different stages in this study. In the first stage, the pavement condition index (PCI) values of the roads were observed from the field surveys and the roads need upgradation works to be identified. The facility indices for habitations were calculated by the spatial analysis and prioritization of the links for upgradation work is done in the second stage using gravity formula. The volume of information related to a rural road is difficult to process, manage, update, and sort; to obviate these difficulties, it is, therefore, considered necessary to develop all the spatial and attribute data in digital format. Therefore, GIS an essential tool in comprehending the information of spatial and non-spatial data over a space and time is employed.

Methodology

The proposed methodology can be divided into different phases. The first phase includes identification of roads for upgradation and maintenance based on the PCI of a road and identifying the village and facilities location using GPS from field observations. The pavement condition index values are assigned to the roads based on the comfortable speed of the vehicle traveled on the road and PCI values are indexed on a scale from 1 to 5 as shown in Table 1, where '1' shows worst possible condition and '5' shows the best possible condition of the pavement (PMGSY Manual). In the present study, comfortable speed of the vehicle observed from the field surveys by traveling on each road twice in a year, i.e., before and after the rainy season in both the direction and car was used as a design vehicle. The average value of the speed considers as a normal driving speed of the vehicle.

Table 1 Assessment of PCI based on comfortable normal driving speed of the vehicle

Normal driving speed (Km/h)	PCI	Description of surface condition
Over 40	5	Very good
30–40	4	Good
20–30	3	Fair
10–20	2	Poor
Less than 10	1	Very poor

After collecting the data from the field observation spatial database was prepared in the Geo-environment using ArcGIS. In the second stage, the facility index values of the habitations are estimated from the facility availability and distance from the facilities to habitation in the study area by spatial analysis tool using ArcGIS software and prioritization list is prepared for upgradation work for the roads based on the link weightage.

Study area and data collection

Dharmasagr Mandal is selected as the study area, which is located in Warangal district of Telangana state. The connectivity status of the study area is shown in Fig. 1. The study area has a total road length of 267.10 km and 78 % connectivity to the habitations. Primary data were collected from field surveys which are conducted in the study area and then data which collected included the elements listed below:

1. Length of each link
2. Average travel time on link
3. Pavement condition of link
4. Type of road
5. Pavement details
6. Location and details of facilities
7. Identification of critical links
8. Missing links in map
9. Population benefited by each link

Handheld GPS instrument was used to collect the location of facilities and trace out the road in the study area. Secondary data like toposheet, habitation details as well as road information data and other ancillary data were collected from Panchayat Raj department of Warangal district. Survey of India (SOI) topographic sheet of 1:50,000 scales used to prepare different layers of the study area.

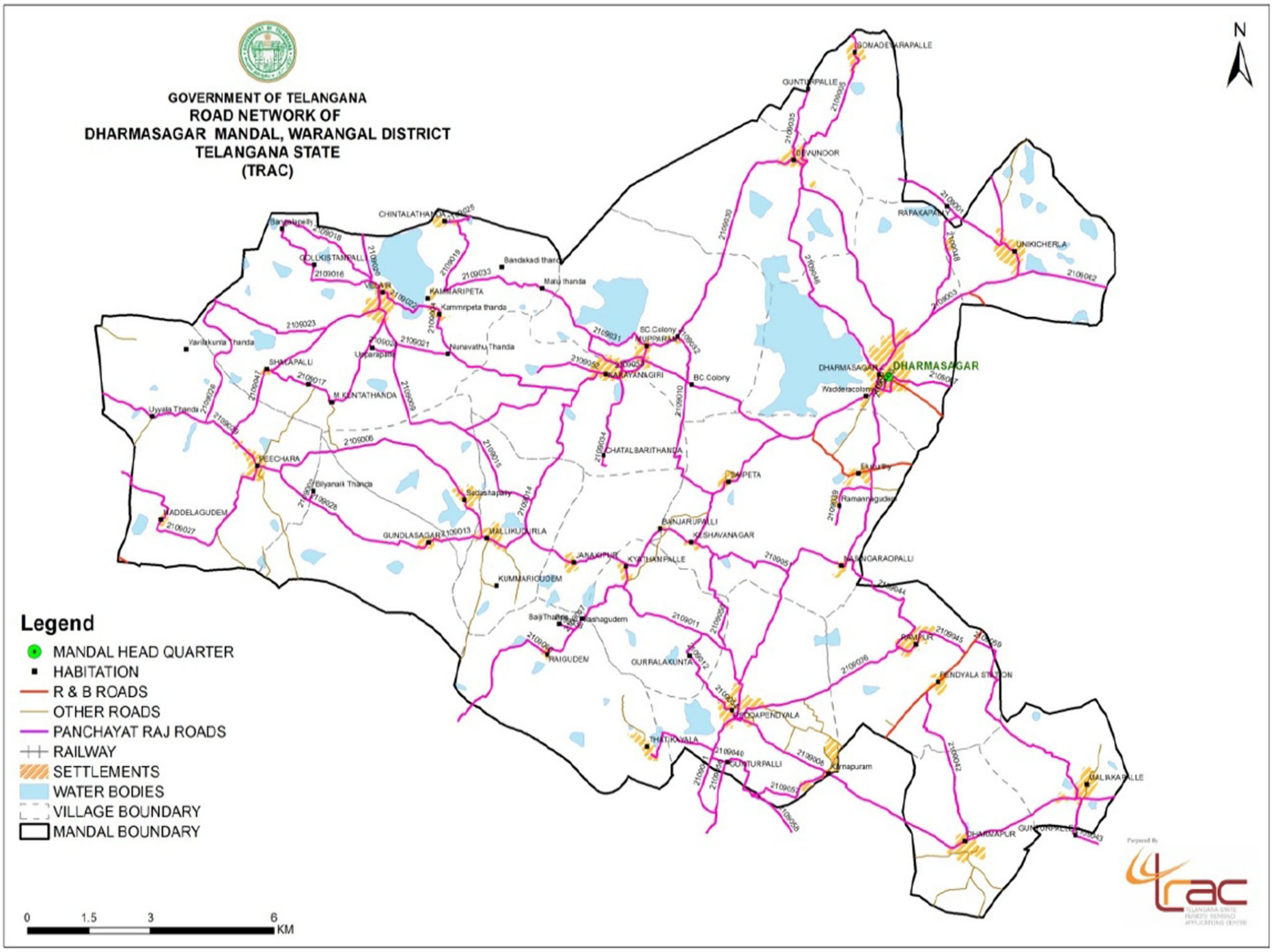

Fig. 1 Connectivity status of the study area

Identification of the roads for upgradation work

To identify the roads to be upgraded field, surveys were conducted in the study area by traveling along the road in a design vehicle with a comfortable riding quality and observed the normal driving speed on the road. PCI values are assigned to the roads based on the normal driving speed as explained in Table 1 and the road connected to habitations was observed for upgradation as listed in Table 2 and the roads which are listed having the PCI value less than or equal to 2.

Preparation of spatial database

Spatial data store geometric locations of geographic features along with attribute information describing what these features represent. Spatial data are usually stored as coordinates and topology, which can be mapped. It is often accessed, manipulated or analyzed through GIS. Spatial information is necessary to specify the shape and location of geographic features as well as spatial relationships between such features. The spatial relationships implicit on a map determine what the map conveys to the reader. For

Table 2 Roads connected to habitations for upgradation work

S. no.	From habitation	To habitation
1	Velair	Gundlasagar
2	Velair	Banglapally (Katkur Ramaiahpalle)
3	Kammaripet	Chinthalathanda
4	Chinthalathanda	Bhilyanaik thanda
5	Kammaripet thanda	Mallikudurla
6	Dharmasagar	Kammaripet thanda
7	Dharmasagar	Karunapuram
8	Dharmasagar	Shodasapally
9	Waddera colony	Thatikayala
10	Elukurthi	Mallakkapally
11	Upparapally	Saipeta

example, tasks such as finding the route between points can be easily accomplished. GIS programs also allow one to complete these tasks.

To prepare the spatial database, preliminary, SOI map of scale 1: 50,000 for the study area collected from Panchayat Raj Department of Warangal District. The map was scanned and entered into the GIS environment for registration purpose. After Geo-referencing, different features of the study area were digitized as different layers. These layers were created in Arc Catalog environment according to the feature type; point layer for the location of habitations, rural infrastructures, etc., polygon for a Mandal boundary, and line for road and other linear features. The road which was traced out from the field using GPS instrument was imported into the map and digitized as a line feature. The shape files were created for various layers with the same coordinate system. The scanned toposheet was defined to this coordinate system before Geo-referencing is done. Once the required shape files of different layers are created, digitization of features is done. Digitization is the process of converting the geographic features on an analog map into digital format. In this process, the *x*, *y* coordinates of these features are automatically recorded and stored as spatial data. The spatial data were created in Arc Map environment and the total spatial database organization involved the process of identifying the content of spatial data and the actual process of creating the database in Arc Catalog.

Preparation of non-spatial database

Non-spatial data are tabular or textual data describing the geographic characteristics of features. This type of data has no specific location in space. It can, however, have a geographic component and be linked to a geographic location. The attribute data can be stored in Excel or Access spreadsheets and joined to their corresponding spatial features using GIS capability. The data were entered into the database for all features collected via field survey and digitized from toposheet. The database contains all fields for which the data were collected from the facility, availability of the block which is in the study area, information collected about the roads inventories, pavement details, habitations, rural infrastructures, etc., the database was developed and

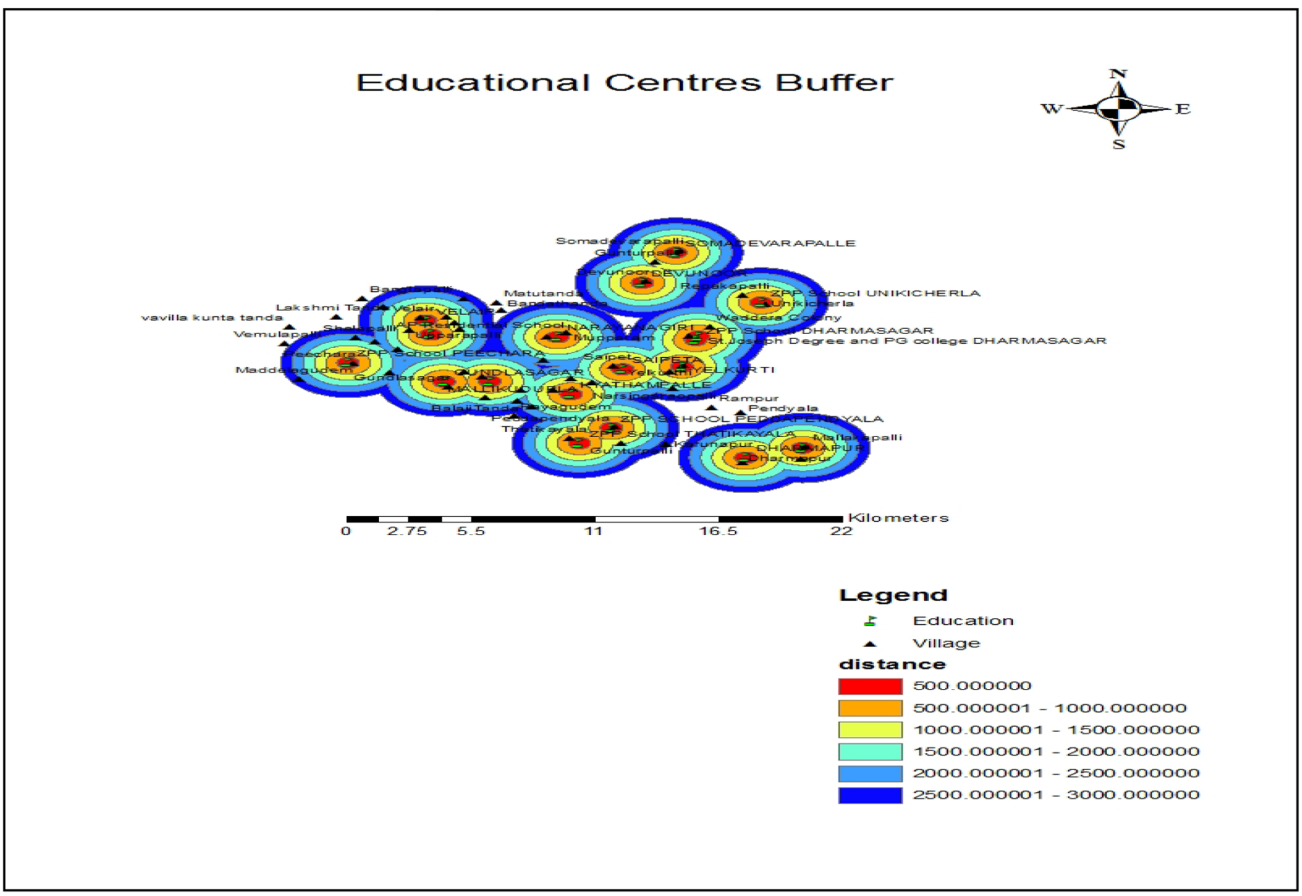

Fig. 2 Accessibility levels from the high school facility

stored on Arc Catalog package. This database shows the real-time attributes to analyze the features.

Spatial and non-spatial database are integrated to form Geo-database. The geo-database is the common data storage and management framework for ArcGIS. It combines "geo" (spatial data) with "database" (data repository) to create a central data repository for spatial data storage and management.

Estimation of village facility index (VFI)

Facility index of a village refers to the level of infrastructure availability from the habitations. The facilities considered for the analysis is given below:

1. Education facilities: it includes a primary school, middle school, high school, an intermediate college, degree college.
2. Medical facilities: it includes sub-centers, maternity, child welfare centers, primary health centers, and hospitals.
3. Economic activity centers: it includes markets, petrol bunks, retail shops, cold storages.
4. Transport and communication facilities: it includes bus stand, railway station, post office, banks, electrical substations, etc.

For each major facility, most popular and widely accepted approach is to find cumulative weight by assigning weights to each parameter under that major facility.

Garg [9], if I_i is the index of particular facility "f" of ith habitation, then the facility index is estimated using Eq. 1.

$$I_i = \sum_j \binom{n}{1} W_j X_j, \quad (1)$$

where W_j: weight of jth sub facility: $w_j \times d_j$

$$w_j = \frac{\text{Total no. of villages in block}}{\text{Villages having jth sub facility}}$$

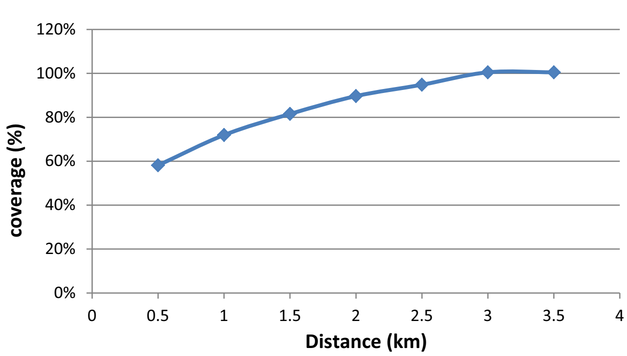

Fig. 3 Effect of coverage in service distance from primary school

X_j: value or availability of jth sub facility in ith habitation; n: number of sub facility available in ith habitation; d_j: distance factor, values are considering as 1, 0.5, 0.0 if these facilities are available only at a distance of less than 0.5 km, in between 0.5 km and maximum coverage distance of the facility, more than maximum coverage distance of the facility, respectively.

The Village Facility Index (VFI) value is obtained by cumulating all the major facility indices shown in Eq. 2.

$$\text{VFI} = \text{EFI} + \text{MFI} + \text{ECOFI} + \text{TFI} + \text{CFI}, \quad (2)$$

where

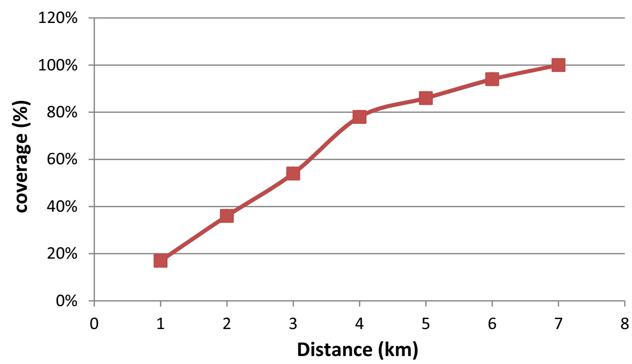

Fig. 4 Effect of coverage in service distance from high school

Table 3 Coverage distances for different facilities

S. no.	Type of facility	MCDF (km)
1	Education facilities	
	Primary school	2
	Middle school	3
	High school	4
	ITI/junior college/degree college	5
2	Health facilities	
	ANM centers	3
	PHC	5
	Veterinary hospital	4
	Community health Center	5
3	Economic activity centers	
	Retail shops	1
	Cold storage	5
	Market	5
4	Transportation and communication centers	
	Railway station	5
	Bus stand	1
	Post office	3
	Banks	5
	Petrol outlet	5
	Electric substation 11kv	5

EFI: educational facility index; MFI: medical facility index; ECOFFI: economic activity facility index; TFI: transportation facility index; CFI: communication facility index.

Identifying the maximum coverage distance from the facility (MCDF)

Maximum coverage distance is the distance at which the facility covers more habitations. In this study, the MCDF values are identified based on the availability of the infrastructure and at what desired distance the facility covers the maximum habituations. Fixing a maximum coverage service distance is a strategic decision. The maximum coverage distance is fixed in the ranges from 0.5 to 5 km. The value corresponds to the average human walking speed which is 5 km/h [7]. Relaxing the service distance allows covering much more habitations, but the difficulty to achieve facility rises accordingly, which is not desirable. To identify the MCDF buffer,spatial analysis was carried out for each facility in the Warangal district using ArcGIS software. For example, Fig. 2 shows the accessibility levels of the habitation from the high school. From this analysis, numbers of habitations covered from a facility at different distance levels are noticed.

Figure 3 shows the covering percentage of the habitations at different service distance from a primary school. The figure shows that more than 50 % of the habitations are covered in less than 0.5 km and then increasing with the lower increment of 14, 10, 8, and 5 % in the distant levels of less than 1, 1.5, 2, and 2.5 km, respectively.

The coverage distance fixed 2 km for the primary school at which more than 80 % habitations are covered. Similarly, the effect of service distance for the high school facility is shown in Fig. 4.

From the Fig. 4, the coverage percentage rapidly increases up to 4 km with nearly 80 % and then increase with lower increments. The coverage distance identified from the analysis for high school is 4 km.

Similarly, the analysis is carried to all the facilities and coverage distances are identified as shown in Table 3.

The MCDF values are considered for calculation of VFI of habitations and the results obtained using Eqs. 1 and 2 are shown in Table 4.

Table 4 Village facility indices of the study area

Name of the habitation	EFI	MFI	TFI	ECOFI	CFI	VFI
Velair	9.87	41.42	1.83	80	1.15	134.27
Upparapally	4.935	20.71	0.915	40	1.075	67.635
Banglapally (Katkur Ramaiahpalle)	5.565	20.71	0.915	40	1.075	68.265
Gollakistampally	5.565	20.71	0.915	40	1.075	68.265
Kammaripet	5.565	20.71	1.83	40	1.075	69.18
Chinthalathanda	5.565	20.71	0.915	40	1.075	68.265
Kammaripet thanda	4.935	20.71	0.915	40	1.075	67.635
Gundlasagar	7.22	7.82	0.915	1	1.075	18.03
Bhilyanaik thanda	6.59	7.82	0.915	1	1.075	17.4
Shodasapally	5.565	7.82	1.83	1	1.15	17.365
Mallikudurla	9.87	15.42	1.83	1	1.075	29.195
Kummarigudem	5.565	7.82	1.83	1	1	17.215
Narayanagiri	9.87	4.82	1.83	1	1	18.52
Devnoor	9.87	4.82	1.83	1	1	18.52
Dharmasagar	115.87	41.42	1.83	27	1.15	187.27
Waddera colony	57.565	20.82	0.915	14	1.075	94.375
Elukurthi	59.22	23.23	1.83	14	1.075	99.355
Narsingaraopally	5.565	2.41	0.915	1	1	10.89
Ramannagudem	5.565	2.41	0.915	1	1	10.89
Saipeta	9.87	2.41	1.83	1	1	16.11
Thatikayala	9.87	10.12	1.83	1	1.15	23.97
Peddapendyala	9.87	15.42	1.83	1	1.15	29.27
Karunapuram	5.565	7.71	1.83	1	1.075	17.18
Mallakkapally	9.87	15.42	1.83	1	1.075	29.195
Gunturpally	4.935	7.71	0.915	1	1.075	15.635

Table 5 Priority list of the roads for upgradation work

S. no.	From habitation	To habitation	Weightage (W_{ij})	Priority of the road
1	Velair	Gundlasagar	9.83	9
2	Velair	Banglapally (Katkur Ramaiahpalle)	48.32	3
3	Kammaripet	Chinthalathanda	0.35	11
4	Chinthalathanda	Bhilyanaik thanda	24.08	5
5	Kammaripet thanda	Mallikudurla	10.14	8
6	Dharmasagar	Kammaripet thanda	470	1
7	Dharmasagar	Karunapuram	23.27	6
8	Dharmasagar	Shodasapally	11.92	7
9	Waddera colony	Thatikayala	9.20	10
10	Elukurthi	Mallakkapally	91.94	2
11	Upparapally	Saipeta	28.72	4

Facility-based model for prioritization of road

The existing rural road planning models in India were developed based on the interaction between the settlements and prioritization of the roads. In the present study, upgradation of the network was done by strengthening the road links by providing the new overlay. Prioritization for upgradation of road link is based on the population benefited by the link, facility index of the villages, and the Pavement Condition Index (PCI) of the road. Facility index values are obtained from the facility availability from the village. Further, the link weight is estimated using the Eq. 3 given below.

$$W_{ij} = \left(P_i \times P_j\right) \left(F_i - F_j\right)/d^2, \qquad (3)$$

where,

Wij: 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: shortest distance between village i and j; if $F_i - F_j = 0$ then take this value as 1

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

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

The result obtained and the priority list of the roads for upgradation work is given in Table 5.

Conclusions

A facility-based model is developed to improve the road condition which is given, due to the consideration, by selecting the road for upgradation based on the link weight and PCI value. Spatial analysis of the facility in the study area helps the organization to understand the influence of the facility of maximum habitations covered from the facility and useful for facility allocation problems. From the spatial analysis of the existing infrastructure in the study area, it is observed that facilities like primary school, Middle school, High school, ANM center, and Post office cover the maximum habitations with in the desirable distance. It shows the accessible levels of these facilities are good in the study area. There is a need to identify the suitable location for providing the public facilities like PHC, cold storage, community health centers, and banks. Rural road organizations can use this model effectively for planning and management of the roads. By upgrading the roads, the travel time on the road can be reduced and the interaction between the habitations can be improved. Even though the model was developed for Indian conditions, it can be practiced in any developing country for planning rural road networks.

References

1. Highway Research Board (1952). Highway sufficiency ratings. HRB Bulletin 228, Washington, DC
2. Makarachi AK, Tillotson HT (1991) Road planning in rural areas of developing countries. Eur J Oper Res 53:279–287

3. Ifzal Ali, Ernesto Pernia M (2003) Infrastructure and poverty reduction: what is the connection?. Asian Development Bank, Manila
4. Shrestha CB (2003) Developing a computer-aided methodology for district road network planning and prioritization in Nepal. Trans Res Board 3:157–174
5. Singh AK (2010) GIS based rural road network planning for developing countries. J Transp Eng 1943–5436:0000212
6. Dhamaniya A (2013) Methodology of maintenance criteria of PMGSY roads in second phase of planning—a case study. J Indian Soc Remote Sens. doi:10.1007/s12524-013-0338-4
7. Shrestha J, Benta A (2013) Multi-objective analysis of cost and social benefits in rural road networks. Int J Civ Environ Struct Constr Archit Eng 7(7)
8. Kumar A, Kumar P (1999) User-friendly model for planning rural roads. J Trans Res Board. doi:10.3141/1652-05
9. Garg (2008) spatial planning of infrastructural facilities in rural area around roorke, Uttarakand, India. Proceedings. FIG working week, Integrating Generations, Stockholm, Sweden, June 14–19