Sustainable rural road network planning with a balance of urban and rural development

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Abstract. Rural roads are the backbone to any country and is always a key for sustainable development. Rural roads are often considered as an entry point for poverty alleviation and employment generation. Rural Connectivity is achieved in different levels of hierarchy through a traditional hierarchical structure – National Highways, State Highways, Major District Roads, Other District roads and Village roads for achieving a long term objective of adequate road communication in India. The policies for connectivity of villages are followed mainly by population criteria. The connectivity through hierarchy is to be planned from the travel behaviour and activity generation, which depends on various profiles like demographic, socio – economic profiles, facility profile and the impedance values. This methodology proposes a strategic model that characterizes the varying profiles in an area and accounts the demand based on these profiles. An integrated model based on clustering analysis and GIS has been formulated for assessing the demand potential and thereby giving an orientation to a hierarchal rural road network configuration. This promises to be scientific tool as it was validated with the existing higher order road network such as National and State highways in the region. The study has been attempted on Medak district of Telangana state.

1. Introduction

With 70% of the global population estimated to be converted to urban areas due to globalisation in the coming years, urban fabrics are the role changers in the contemporary society. There is a growing pressure built on the cities with respect to land utilisation, resources, energy, water, clean air posing environmental threats. Equally, the opportunities created for the people livelihoods and the quality of living in the urban areas cannot be understated [1, 2]. Urban areas and their ever steeping developments provide socio- economic interactions between the humans that are promising for achieving sustainable development goals. However, rural areas have more access to the natural resources where agriculture production is crucial for developing countries like India. The development of rural roads should provide connectivity and accessibility to all villages that makes the social interactions more evident [3]. The transformation from rural to urban areas must be smooth with an equitable balance of both the developments. The diversity is to be maintained for promoting an environmentally sustainable and economical solutions in planning.

Rural roads have suffered greatly due to lack of systematic planning. While rural road development plans provided for a network structure and target lengths of different types of roads, specific connectivity requirements of individual settlements (villages/habitation) and issues of regional imbalances were not adequately addressed. This led to more than one connection for the same village resulting in redundancy and development of a large unmanageable network. Since basic issue of urban and rural transportation planning is different, the urban transportation models, which have reached into the advanced level, can be hardly replicated for planning the rural transportation network. Therefore, this study intends to contribute towards providing a theoretically sound and practically applicable model for generating rural
road networks in the developing countries. There is a need to develop Integrated Rural road planning that comprises a set of planning procedures that look at access, transport and mobility from a broader perspective to achieve sustainable development.

There have been extensive studies conducted for rural road development at National level and International level. Ali and Shaheen (2017) have structurally evaluated the rural road network with various indices of connectivity and have done shortest path analysis to identify the rural hubs and provide scope for rural road development [4]. Kumar and Tillotson (1991) developed a planning model that generates a basic rural road network providing access to each village to a larger center of activities for marketing, health, education, trade, commerce, and social welfare [5]. Shalini et al (2017) has developed a need based approach in GIS for rural road network which is based on demand in the area [6]. Anjaneulu et al. (2007), used secondary data sources for planning rural road network based on functional dependencies of settlement and potential interactions resulting from them [7]. In most of the studies, hierarchy was not properly addressed and there was discontinuity in providing an integrated network for an area. This study provides a planning strategy and tool for addressing the hierarchy needs in rural areas.

2. Objectives of the study
Following are the objectives of this study.
1. To develop a methodology which can identify uniform road connectivity for the compatible development of the area with GIS as a supporting tool.
2. Develop a framework for rural road transportation planning to achieve a balance in urban and rural development using clustering.
3. Maximization of utilization of natural resources for road network orientation.
4. Promote positive interaction between urbanization and the building of a new countryside.
5. Develop an approach to strengthen country’s infrastructure by sustained environmental protection and guide for an orderly development of rural areas.
6. Application of clustering concepts in developing interrelationships between transportation and demographic, socio-economic variables for sustainable planning.

Assumptions in the study are as follows.
1. Demand potential is considered as proxy to travel demand
2. Facility scores that indicate the potential of demand are determined based on the World Bank guidelines
3. The demand potential attributes are assumed to represent the relative importance of a village.
4. The scores of village are obtained by taking the demographic, Socio-economic factors and infrastructural facilities of that particular location into consideration.
5. The attribute data is considered to be uniform throughout the village.

3. Methodology
Demand potential / Travel patronage are to be considered in view of the generation of the activities in an area. Activity generation in rural areas is a function of many multifaceted factors such as demographic, socio economic characteristics, availability of facilities and the distance of a village from the market centre. It is obvious that all the villages in a mandal / a district do not exhibit similar characteristics. This unique nature in terms of travel patronage is difficult to handle in planning a network. But these characteristics which influence the travel can be grouped in some categories to represent a cluster of common behaviour. The network can then be planned based on these categories of villages as it becomes difficult to propose a connectivity pattern for each village in a mandal. The planning of a network through the clustering analysis will serve as a scientific tool in the hands of a planner to achieve the desired level of connectivity. Clustering analysis is thus useful in grouping the villages, which show similar demographic and socio economic characteristics. But in order to propose
connectivity patterns, there is a need to prioritize the categories and to know the demand potential of each category compared to the other categories. Each cluster is governed by multiple parameters, which generate an activity in an area. The activity generation is a function of demographic and socio economic characteristics of the region, facility profile of the area and distance from the market centre. The demand potential of a category with respect to activity generation is determined using the k-means clustering technique in terms of the cluster number. The specific objectives in the study would be to develop a connectivity pattern in a network configuration which aims to give preference for the villages with maximum population, maximum number of workers, maximum agricultural labourers, maximum number of facilities available, and maximum number of households, maximum number of production units and which bears minimum distance from the market centre. Hence each village is grouped into a cluster that bears uniform characteristics.

The methodological framework for the study has been split into following phases

1. Phase 1: Identification of activity generation attributes in the study area.
2. Phase 2: Development of GIS base map using SOI toposheets, revenue maps, satellite imagery
3. Phase 3: Delineation of villages.
4. Phase 4: Development of database for demand potential attributes for each village from Demographic and socio economic characteristics.
5. Phase 5: Development of facility score of each village in the district from the facility profile of each category that includes facilities like educational, medical, drinking water, electricity etc.
6. Phase 6: Categorization of villages using k-means clustering using MINITAB.
7. Phase 7: Integration of cluster number obtained from k-means clustering technique to GIS base map.
8. Phase 8: Validation of cluster with the demand potential attributes
9. Phase 9: Overlay of cluster profiles and existing road network configuration
10. Phase 10: Development of proposed road network configuration based on clusters in GIS

In Phase 1, the activity generation attributes in the study area are identified that depend on the various profiles in an area like the demographic profile, socio economic profile, facility profile, land-use characteristics, and the impedance characteristics. The attributes which are identified are site specific based on the travel behaviour and the travel patronage. The data has been collected from census data where the profiles of each village are listed. In Phase 2, the base map representing the road network is developed revenue division wise and is integrated using GIS and GPS as supporting tools. The revenue division maps and Survey of India (SOI) toposheets of the entire district have been digitised, spatially referenced and mosaiced in a GIS environment to form a GIS base map. ARCGIS 10.1 has been used in the process. The spatial referencing of SOI toposheets is available, but revenue division maps had to be referenced with the common points identified from both the maps in GIS. The data has been updated from the satellite imageries (Source: Google earth) with the road network. In Phase 3, delineation of villages is done by entering a unique code for each village in GIS that should match with the attribute data entered in database. In phase 4, the database for demand potential attributes for each village is developed matching the unique code given to each village. The attributes pertain to the various profiles identified in phase 1. In Phase 5, facility score of each village in the district is developed from the facility profile of each category that includes facilities like educational, medical, drinking water, electricity etc. by a unique scoring pattern. These scores are unique in value and it represents the relative inherent strength or potential of that village among set of other villages in developing accessibility to the other areas. Thus the priority of that village amongst the other villages is determined. In Phase 6, categorization of villages into 4 clusters using k-means clustering is done using MINITAB software. The procedure of clustering cannot be represented in a two dimensional frame, a support from MINITAB software is taken that has the capability of analysing the parameters in multi-dimensional framework. In Phase 7, cluster number obtained from k-means clustering technique is integrated to GIS
base map using Join tool in GIS. This provides a lead to the thematic mapping of the cluster number that helped to view the variation and distribution of the behaviour of the demand generating attributes in a spatial frame. In Phase 8, cluster number obtained from k-means clustering is validated with the demand potential attributes / input variables to observe the trend of each parameter with the allocated cluster. In Phase 9, overlay of cluster profiles and existing road network configuration is done to propose a new network in line with the existing network. In Phase 10, proposed road network configuration is developed based on clusters in GIS.

4. Study area

The study area is selected based on the potential of its development that has varied demographic profile and socio-economic profile characteristics. The area taken into consideration is Medak district, Telangana, India. The study area includes 3 revenue divisions which comprises of the 46 Mandals. These Mandals all together consists of 1263 villages. Few of these villages are connected to nearest National way and State highway rest of the villages still remain unconnected leading to the migration of the rural people from these villages. The attributes were given to the villages based on the demographic profile, socio-economic profile, and facility profile and so on. The attributes which are identified are site specific based on the travel behaviour and the travel patronage. The data has been collected from census data where the profiles of each village are listed.

The base map generated for the study area is shown in figure 1.

![Figure 1. Base map of study area.](image)

The Geo-referencing of the maps and mosaicing of both toposheets from SOI and Revenue divisions is done. The delineation of villages is made by giving a unique code for each village in ARCGIS. This is done by creating a field “CODE” in the village polygons. The attribute code is now added to all the villages in the district. The base maps after adding the unique code are shown for the three revenue divisions from figure 2.
5. Application of methodology

The demand potential of the village is determined from the activity generation attributes of each village. These attributes indicate the potential to travel demand in the area. The activity generation attributes in the study area are identified that depend on the various profiles in an area like the demographic profile, socio-economic profile, facility profile, land-use characteristics, and the impedance characteristics. The attributes which are identified are site-specific based on the travel behaviour and the travel patronage.

Following table 1 are the demand potential attributes that are identified for assessment of demand potential of each village.

Table 1 Demand potential attributes of each village

| SNO | Name of the attribute | Description |
|-----|-----------------------|-------------|
| 1   | Population            | The total population of each village |
| 2   | households            | The number of households in each village |
| 3   | Distance              | Distance from the nearest town in km |
| 4   | cultivators           | Number of cultivators |
| 5   | labourers             | Number of labourers |
| 6   | literates             | Number of literates |
| 7   | Irrigated _ area      | Irrigated land area in sq.km |
| 8   | Area                  | Area of the village in sq.km |
| 9   | workers               | Number of agricultural workers |
| 10  | Road_length           | Road length covered in each village determined from the core network length and SOI. |
| 11  | Facility_score        | Score determined from the amenities available in each village based on World bank guidelines |
| 12  | MPSRH                 | Number of people working in Manufacturing, processing, servicing and repairs in household industries |
| 13  | MPSROH                | Number of people working in manufacturing, processing, servicing and repairs in other than household industries |
The data of the above attributes is obtained from the census book and is entered in DBMS software. Along with this data, the unique code pertaining to each village in GIS is also created in DBMS. The facility score is determined from the available facilities in the village.

The facility score of each village in the district is developed from the facility profile of each category that includes facilities like educational, medical, drinking water, electricity etc. by a unique scoring pattern shown in table 2. (Source: World bank guidelines [8]). These scores are unique in value and it represents the relative inherent strength or potential of that village among set of other villages in developing accessibility to the other areas. Thus the priority of that village amongst the other villages is determined. The various facilities available in the village are obtained from the census records and the data processing is done by assigning a set of points to the various facilities available in a village by a unique scoring pattern. A road need assessment rating is used to rank the qualifying roads to establish priority of intervention. The cumulative score of all the facilities is considered as the force of the village. These scores which are unique in nature represent the force of that particular village. In other words, it represents the relative inherent strength or potential of that village among a set of other villages, in developing its accessibility to the mandal Head Quarters. Thus the priority of that village amongst the cluster of villages is determined.

Table 2 Road Need Assessment Rating

| SECTOR         | FACILITY                          | POINT |
|----------------|-----------------------------------|-------|
| **Educational**| P: Primary or Elementary School   | 05    |
|                | (up to Class IV )                 |       |
|                | M: Middle School or Junior Secondary | 10   |
|                | (Class V to VIII )                |       |
|                | H: Matriculation or Secondary     | 15    |
|                | School (Class IX and X)           |       |
|                | JC: Higher Secondary / PUC        | 20    |
|                | C: College (graduate level and above) | 25  |
|                | I: Industrial School              | 30    |
|                | Tr: Training School               | 50    |
|                | Ac: Adult literacy class /Center  | 50    |
|                | O: Others                         | 20    |
|                | When Educational facility is available at a distance of : |       |
|                | - less than 5 kms                 | 15    |
|                | - 5 to 10 kms                     | 10    |
|                | - 10+ kms                         | 05    |
| **Communication**| BS: Bus Stop                     | 25    |
|                | RS: Railway Station               | 50    |
|                | NW: Navigable Waterway           | 20    |
|                | When Communications facility is available at a distance of : |       |
|                | - less than 5 kms                 | 20    |
|                | - 5-10 kms                        | 15    |
|                | - 10+ kms                         | 10    |
| **Post & Telegraph**| PO: Post office                  | 25    |
|                 | TO: Telegraph office              | 25    |
|                 | PTO: Post & Telegraph office      | 50    |
|                 | Phone: Telephone connection       | 75    |
|                 | When Facility is available at a distance of: |       |
|                 | - less than 5 kms                 | 20    |
|                 | - 5 to 10 kms                     | 15    |
|                 | - 10+ kms                         | 10    |
|                 | TW: Tube Well                     | 30    |
When drinking water facility is available at distance of,
- less than 5km
- 5 to 10kms
- 10+kms

Approach to the Village
- PR: Pucca road
- KR: Kachcha road
- FP: Foot path
- NR: Navigable river
- NC: Navigable canal
- NW: Navigable Waterway

Power Supply
- ED: Electricity for Domestic purpose only
- EAG: Electricity for agriculture purpose only
- EO:Electricity for other purpose like, industrial commercial etc.,
- EA: Electricity for all purpose listed above

Land Use
- Culturable Waste:
  - More culturable waste, Less points
  - Less culturable waste, More points
- Area not available for Cultivation:
  - More area, Less Points
  - Less area, More Points

Households and Population
- More people, more households-more points
- Less people, less number of households-less points

The distribution of the facility score over the spatial frame is shown in figure 3 below.
unique code that has been attached to each village in spatial data and attribute data. The clustering of
villages based on the demand potential attributes is done using k-means clustering technique. Since there
are 13 demand potential attributes that are considered, they have to be analysed in 13 dimensions. Hence
this has been analysed in MINITAB software.

Table 3 Cluster characteristics

| Cluster   | Number of observations | Within cluster sum of squares | Average distance from centroid | maximum distance from centroid |
|-----------|------------------------|-------------------------------|-------------------------------|-------------------------------|
| Cluster1  | 77                     | 2.05E+08                      | 1427.395                      | 4094.164                      |
| Cluster2  | 8                      | 3.72E+07                      | 1941.166                      | 3988.984                      |
| Cluster3  | 767                    | 3.08E+08                      | 539.716                       | 5393.838                      |
| Cluster4  | 379                    | 2.71E+08                      | 768.217                       | 2770.441                      |

The cluster centroids of each variable from table 3 is given in table 4.

Table 4 Cluster centroids of each variable

| Variable                        | Cluster1     | Cluster2     | Cluster3     | Cluster4     |
|---------------------------------|--------------|--------------|--------------|--------------|
| TOTAL LENGTH                    | 11.8983      | 15.2613      | 3.2685       | 6.625        |
| TOTAL AREA IN HECTARES          | 1794.63      | 2003.393     | 489.377      | 1051.43      |
| TOTAL NO.OF HOUSEHOLDS          | 908.506      | 1949.5       | 143.426      | 393.989      |
| POPULATION                      | 4757.03      | 11027.8      | 786.837      | 2168.54      |
| AMENITIES AVAILABLE             | 244.441      | 542.5        | 117.157      | 171.248      |
| DISTANCE FROM NEAREST TOWN(KM)  | 20.9351      | 22.5         | 23.2047      | 22.4565      |
| LAND USE(IRRIGATED BY SOURCE)   | 322.886      | 379.667      | 76.0295      | 169.436      |
| TOTAL MAIN WORKERS              | 2278.03      | 4081.37      | 399.176      | 1089.01      |
| CULTIVATORS                     | 823.467      | 848.75       | 196.696      | 477.554      |
| AGRICULTURAL LABOURS            | 851.766      | 1279.75      | 161.933      | 423.205      |
| REPAIRS IN HOUSEHOLD INDUSTRY   | 85.8052      | 2.17E+02     | 6.5606       | 35.0475      |
| REPAIRS IN OTHER THAN HOUSEHOLD | 213.2597     | 4.69E+02     | 11.5802      | 48.6016      |

The cluster number obtained from MINITAB is attached to GIS through Join and Relate option in GIS
with the primary key as the CODE of each village. A thematic map of the villages indicating cluster is
shown in figure 4.
Figure 4. Thematic map indicating cluster of the study area.
The cluster number obtained from k-mean clustering technique considering the demand potential attributes is validated with the existing road network by the overlay analysis of cluster thematic map and existing road network map. The thematic map of cluster in each village is overlaid with existing road network is shown in figure 5

Figure 5. Validation of cluster number with existing higher order network.
Figure 5 indicates that the higher order network is passing through cluster 1 village. This indicates that the progress of growth network and demand potential are moving at the same pace. The proposed road network configuration is developed based on clusters in GIS. The villages in higher clusters like 1 and 2 are connected to the Highways and villages in lower cluster 3 and 4 are connected to the roads
connected in the previous case. The proposed road network configuration from cluster analysis is shown in figure 6.

Figure 6. Proposed road network configuration based on the cluster number.

The final road network configuration in coordination with existing road network is shown in figure 7.

Figure 7. Final road network configuration of study area
6. Findings of the study
1. Existing road length in the Medak district is 6056 km
2. The cluster number 1 indicates high potential villages where the demand for travel is more. This has been validated with the overlay of existing higher order road network on the thematic cluster map. The existing National Highway and State Highway were passing through cluster 1 villages.
3. Number of villages that fall under cluster 1 are 77, cluster 2 are 8, cluster 3 are 767 and cluster 4 are 379.
4. The marginal plots of all demand potential variables for various cluster demonstrated the same trend
5. The proposed road length of cluster 1 villages is 333.8 Km, cluster 2 villages is 46.5 km, cluster 3 villages is 1006. Km, cluster 4 villages is 899. Km.

7. Conclusion
Following are the conclusions in the study
a. This study provided a scientific tool for development of rural road network configuration based on clustering the villages as per the potential and providing a uniform connectivity pattern through the inherent hierarchy in the clusters.
b. This has resulted in a holistic development of the region where diverse attributes instigating a travel demand exist.
c. The approach can be generalised in applying to rural areas in developing economies that are in verge of transforming into urban areas where developments pays a strong penalty in losing the resources and involves huge economic and social costs.
d. This tool would provide a balance in development promoting sustainable rural fabrics and maintaining the pace of hierarchy within the network structure and also in the growth patterns.
e. This study has provided an approach that does not disturb rural positive and sustainable interactions and promotes an integrated network that can balance the urban growths.

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