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Road Network Analysis Using Different Centrality Measures

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Abstract— In this modern era, though we have reached the heights of technology, there are still many countries with a vast population where the necessities of people are not appropriately met. There is no efficient traffic control, no adequate schools, hospitals, and many other emergency services in the right place. Advertising to the same distribution should be fair so that citizens from that region or adjacent regions can access services without facing any issues. Network Analysis of Road networks can help to analyze the city's public transportation and connectivity of various places effectively. In this work, network analysis is done on a Metropolitan city in India named 'Hyderabad' and the national highway road network in India. The performance metrics of the Road network are determined based on different centrality measures such as degree, edge-betweenness, betweenness, and eigenvector centralities. This work will provide a very clear description of the road network's negative and positive impacts. These centrality measures help determine the narrow road junctions and the location of public services in the city.

Key words: Road Network, centrality, Network Analysis, degree centrality

I. Introduction

Recently, with the rapid growth of the population, many cities have inadequate public services such as hospitals, police stations, ATMs, etc. [1]. Because of accelerated urbanization and higher infrastructure, the provision of public services is increased. Citizens in the country also face many issues related to traffic and congestion due to inadequate road network connectivity. If public services are located where people can access the infrastructure easily, it can help the community in a better way. The transformation of road networks into efficient ways leads to a reduction in traffic congestion. Network analysis of road networks can give a clear picture of it.

The Social Network analysis is to understand and analyze the massive data used in Networks [2,3]. The network consists of nodes and edges where nodes indicate the state and edges mean the relationship/connection between the nodes [4,5]. It is necessary to distinguish the most critical nodes of a network with the help of centrality measures. Those important nodes can be more effective and stable [6].

Network analysis helps define essential nodes and connections, which can be further used to decrease traffic congestion problems and improper distribution of public services [7,8]. This work is an endeavour to examine a road network through centrality measures to propose modifications in the architecture of that particular network [9]. There are lots of applications for the network analysis which can help us to find the key places in the urban network using different algorithms to establish the services.

In the proposed work, network analysis is performed on the city in India named 'Hyderabad' and National Highway Road Network. It helps find bottle-necked junctions and bottle-necked roads that can be relaxed to decrease traffic congestion problems. It also helps find optimal places in the road network to establish public services. The methodology includes various stages. Data is scraped from google. Data is analyzed, and various centrality measures are applied to road networks. The obtained results are compared, and graphs are plotted to draw specific critical features.

II. LITERATURE REVIEW

The transportation system in cities with high traffic volume and their reliability, performance, safety, comfort, and accessibility are indicators of public transportation quality [10]. The traffic demand in Major cities is continuously increasing, which results in complex road Networks and intricate road junctions [11,12]. Also, the concept of complex networks has become popular recently because of the fascinating discovery of several Universal properties in different physical and artificial networks [13]. Results from studies on complex networks are significant for transportation analysis, particularly the provision of suitable analytical methods to describe the structure of road systems. These are practical network forms for understanding the operation of a complex system like Road Networks [14].

Over the next decade, travel demand measured over vehicles-kilometres will increase by more than seventeen percent. Building new roads would only boost road space by about four percent [15]. Aust roads, an organization of state road authorities in Australia, published the road network's performance indicators, including Travel speed, Reliability, productivity, etc., [16]. These Performance indicators can be used for managing road networks. Managing road networks is becoming more critical rather than constructing new roads. Lack of Management causes delays and environmental issues and impacts public health. The city relies on the quick response of ambulances, Fire-brigades, etc., and network congestion would affect their performance.

Since the 1970s, social network analysis Techniques have developed into one of the internet's popular applications [17].

There are various explanations for a deeper understanding of a social network's function, explaining the need for their review and researching their effect on the future internet [18]. The social network is a relationship network or interactions, where people or actors are the nodes, and the edges or arches are connections or relationships among these actors [19]. Social networks and methods to analyze them have existed for decades. Social Network Analysis (SNA) has been applied to the analytics of big data to find the relationship between social entities, as well as the patterns and implications of these relations [20]. SNA is a strategy for researching social structures using network theories and graph theories [21].

Currently, the growth of social network analysis techniques is rapid. These techniques interest many researchers in various fields, such as sociology, communication and informatics, social psychology, and so on [22]. Analysis of social networks (SNA) applies graph theory to identify, categorize, and measure relationships within the social network. For example, it can be an excellent tool for improving analytical capabilities in any field Marketing analytics, prediction churning, health care, etc. [23].

Researchers are still determining the most critical junction in road networks. In our work, network analysis predicts the most significant and bottlenecked crossings. Our work provides a more detailed description and characteristics of Road junctions. The Information and aspects of road networks are limited. Only Degree centrality is used to analyze networks in previous work, but in our work, various centrality measures are used to analyze road networks.

III. METHODOLOGY

Network analysis is applied to the Metropolitan City Hyderabad City and National Highway Road Network. The workflow includes 5 stages: Data Scraping, Data cleansing, Data Validation, Network analysis, and Data visualization. These stages can lead to knowing the architecture of the road network in an effective way.

A. Data Scraping:

Data scraping is the process used to acquire information from the web into an excel sheet or any other format. It plays a key role in getting data from websites [9]. In this work, data scraping is used for knowing about the places and routes between them. The information on the Highway and Metropolitan City Hyderabad city road network are scraped from Wikipedia which results in two different data.

B. Data Cleansing:

Data cleansing is changing the information of a storage resource or file to ensure that the information is correct and accurate [24]. The Data cleansing technique is applied to the datasets to delete inaccurate, duplicate, or any other error data from the resource datasets. The data cleansing technique is applied to the data available after data scraping which results in data without any errors and other inaccurate values.

C. Data Validation:

Data validation is the process that data have undergone the data cleansing technique to ensure that they have good quality [25]. It means that the data is both correct and useful. The Data validation technique applies some "validation rules" and "validation constraints" on the data to check for correctness and usefulness. Data validation gives the assurance of the data that was gathered is correct and useful for the Analysis. This data validation process makes the data to be good quality datasets.

D. Network Analysis and Data Visualization

The dataset from the data validation phase reaches the Network analysis phase. In this phase, the two Datasets are converted into networks where nodes indicate the places and edges indicate the roads connecting those places.

The algorithms applied to the network map effectively provide benefits [26]. Betweenness centrality, edge betweenness centrality, degree centrality, closeness centrality, and eigenvector centrality measures are applied to the network. This analysis gives various requirements for applications [27]. Degree Centrality is the number of nodes connected to a node. The node with more connecting links will be more central [28]. Betweenness Centrality of a node can be defined as the total number of times the node serves as an interface/bridge along with the narrowest route map between two other nodes [29]. Closeness centrality is a measure of centrality in a network, calculated as the inverse of the summation of the lengths of the shortest paths between a vertex and other vertices in the graph [30]. Eigenvector centrality is a measure of a node's impact on the network. Edge betweenness centrality is defined as the number of shortest paths that go through an edge in the graph [31].

To visualize the network, Gephi software is used; a tool to analyze the data and convert it into the network with nodes and edges [32]. This network generated in it consists of a source, destination, and intermediate places.

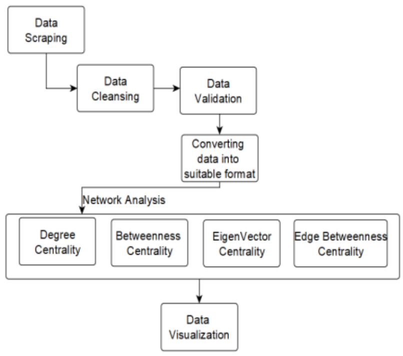

Fig.1. Block Diagram for Network analysis

IV. Results and Discussion

The data collected from the validation process hits the analysis process of the network. These datasets are analysed by converting them into networks. In this section, various centrality measures are applied to two different networks. The results of the analysis are visualised to get a clear overview of the network. The combined effects of centrality measures will describe the road network effectively.

a. Network analysis

The road network data of Metropolitan City Hyderabad city and the National Highway Road Network is visualized as an undirected graph using Gephi software. In Visualised Network, green and red nodes are dead ends of the routes. Similarly, blue nodes are intermediate nodes in a network. In Fig. 2, The nodes in the network represent areas of Metropolitan City Hyderabad city, whereas edges represent roads connecting them. In Fig. 3, nodes represent cities in India and edges are roads connecting them.

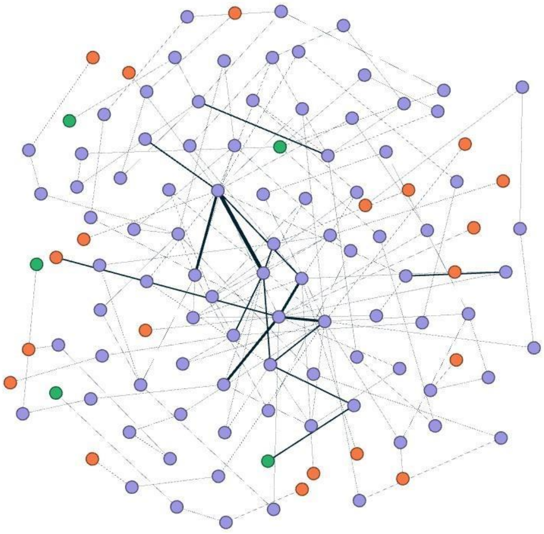

Fig.2. Road Network of Metropolitan City Hyderabad city

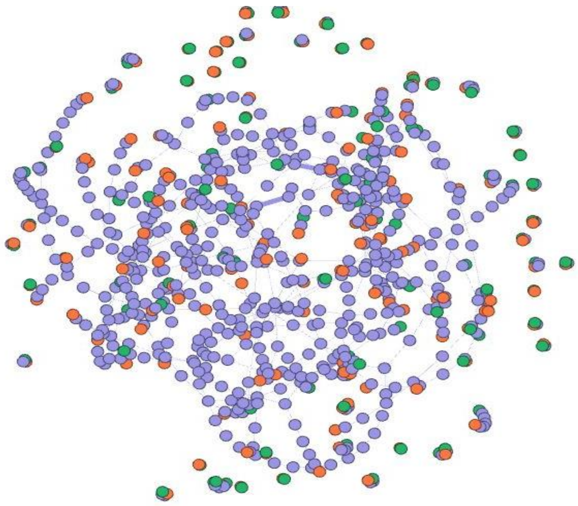

Fig.3. Road Network of National Highway in India.

1)Degree centrality

Degree centrality determines how well the city's area is connected to other areas of a city in the Metropolitan City Hyderabad Network. In contrast, the National Highway road Network shows how well the city is connected in India. The city in India or the area in Metropolitan City Hyderabad with more connectivity has a high degree of centrality value.

In (1) terms define the following

For G (C, R) Network,

C = Node in the network i.e. area

R = Edge in the network i.e. road

N_D=Degree centrality of a node

$$N_D = \frac{deg(C)}{n-1} \quad (1)$$

To understand the calculation of degree centrality, consider the road network of five areas in Metropolitan City Hyderabad named lb nagar, chaitanyapuri, Dilsukhnagar, Malakpet, and Nagole. The below-undirected graph illustrates the road network of these areas.

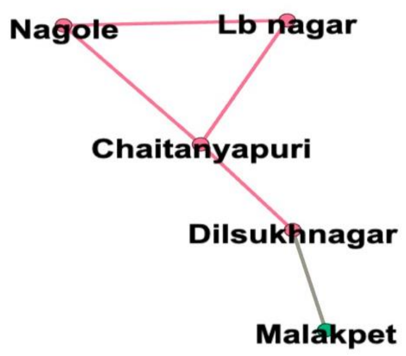

Fig.4. Exemplary road connectivity of a few areas in Metropolitan City Hyderabad.

Here Lb Nagar node is connected to Chaitanyapuri and Nagole, so the Lb Nagar node's degree is 2. Similarly, the degree is calculated for the remaining areas.

TABLE 1. ADJACENCY MATRIX

	Lb Nagar	Chaitany-apuri	Dilsukh-nagar	Malakpe-t	Nagole
Lb Nagar	0	1	0	0	1
Chaitanyapuri	1	0	1	0	1
Dilsukhnagar	0	1	0	1	0
Malakpet	0	0	1	0	0
Nagole	1	1	0	0	0

TABLE 2. DEGREE CENTRALITY MEASURE OF EXEMPLARY AREAS

AREA	Deg(c)	N-1	Degree centrality
Lb Nagar	2	4	2/4=0.5
Chaitanyapuri	3	4	3/4=0.75
Dilsukhnagar	2	4	2/4=0.5
Malakpet	1	4	1/4=0.25
Nagole	2	4	2/4=0.5

In table 2, the Chaitanyapuri area has the highest degree of centrality, followed by Lb Nagar, Dilsukhnagar, Nagole, and Malakpet.

TABLE 3 DEGREE CENTRALITY MEASURE

Metropolitan City Hyderabad Road Network		National Highway Road Network	
Areas	**Values**	**Cities**	**Values**
Charminar	0.12389	Madurai	0.00884
Koti Women's College	0.11504	Jhansi	0.00884
Afzalgunj	0.10619	Delhi	0.00758
Lakdikapool	0.07079	Surat	0.00758
CBS	0.07079	Nagpur	0.00758
Secunderabad	0.05309	Raipur	0.00758
Dilsukhnagar	0.05309	Solapur	0.00758
LB Nagar	0.05309	Coimbatore	0.00758
Mehdipatnam	0.05309	Ambala	0.00758
JBS	0.04424	Banglore	0.00758

The Degree centrality ranges from 0 to 0.12389 in Metropolitan City Hyderabad Road Network and 0 to 0.00884 in the National Highway Road Network. The analysis of two different networks in Table 1 shows how cities or areas in the town are connected among themselves. From Table 3, a place named Charminar in the Metropolitan City Hyderabad road network and cities named Madhurai and Jhansi are highly correlated. Setting up shops/shopping malls in Metropolitan City Hyderabad regions with a high degree of centrality would be more effective.

The histogram in Fig. 5 and Fig. 6 is used to find the distribution of degree centralities of nodes among the different networks. From Fig. 4, nodes in Metropolitan City Hyderabad with a degree centrality around 0.005 are more in number, whereas in Fig. 5, nodes in the country with 0.001 are more significant. Nodes above centrality value 0.015 in the Metropolitan City Hyderabad road network and 0.006 in the National highway road network can be determined as the most critical nodes in their respective networks.

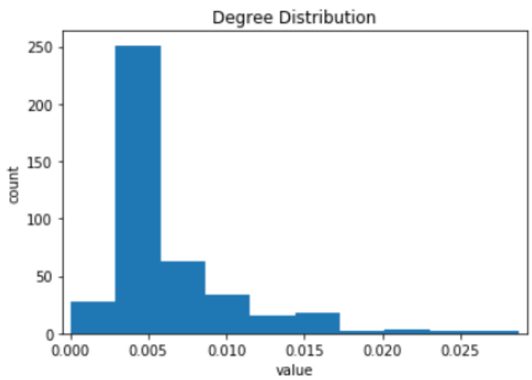

Fig.5. Degree centrality distribution over Metropolitan City Hyderabad city road Network

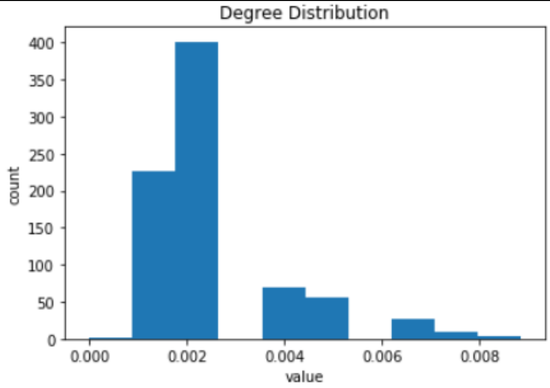

Fig.6. Degree centrality distribution over National Highway Road Network

2)Betweenness Centrality:

For the Metropolitan City Hyderabad road network, It illustrates how one area of town will influence the other areas of town without direct interconnection. An area with a high betweenness value indicates that the node is highly likely to occur on a randomly chosen shortest route between any two odd-picked city areas. Betweenness centrality for a place is the sum of the estimated probabilities over all pairs of areas, not including the area needed to be calculated. For National highway Road Network, it shows how one city can affect other cities without apparent interconnections. A city with a high betweenness value suggests that the node is highly likely to appear on a randomly chosen shortest route between any two uniquely picked cities in India

In (2) terms define the following
For G (C, R) Network,
$\sigma_{ab}(C)$ = Number of shortest paths include node C
σ_{ab} = Number of shortest paths between node ‘a’ and node ‘b’
B_c = Betweenness centrality

$$B_c = \sum_{a\neq b\neq t} \frac{\sigma_{ab}(C)}{\sigma_{ab}} \qquad (2)$$

To understand the calculation of Betweenness centrality, Consider the areas in Fig. 4,

TABLE 4. BETWEENNESS CENTRALITY MEASURE OF EXEMPLARY AREAS

	σ a b	σ a b (c)	$\frac{\sigma_{ab}(C)}{\sigma_{ab}}$
(Nagole, Lb Nagar)	1	0	0
(Nagole, Dilsukhnagar)	1	1	1
(Nagole, Malakpet)	1	1	1
(Lb Nagar, Dilsukhnagar)	1	1	1
(Lb Nagar, Malakpet)	1	1	1
(Dilsukhnagar, Malakpet)	1	0	0

From Table 4, Betweenness centrality of chaitanyapuri is $\sum (\sigma_{ab}(c) / \sigma_{ab}) = 4$. Similarly Betweenness Centrality for all the areas of Metropolitan City Hyderabad and National highway road network in India is calculated.

TABLE 5. BETWEENNESS CENTRALITY MEASURE

Metropolitan City Hyderabad Road Network		National Highway Road Network	
Areas	**Values**	**Cities**	**Values**
Koti Women's College	0.41527	Metropolitan City Hyderabad	0.18956
Charminar	0.37517	Delhi	0.18357
Afzal Gunj	0.30259	Nagpur	0.16343
Secunderabad	0.22942	Jhansi	0.14941
RTC X RDS	0.22641	Kurnool	0.14901
Dilsukhnagar	0.15920	Bangalore	0.14776
JBS	0.13116	Lakhnadon	0.14093
Lakdikapul	0.11837	Ambala	0.13996
LB Nagar	0.08495	Chikkaballapur	0.13811

The Betweenness centrality varies from 0 to 0.41527 in the Metropolitan City Hyderabad city and 0 to 0.18956 in the National highway road network as per Table. 5. Betweenness centrality helps in knowing the bottle-neck junctions in the Metropolitan City Hyderabad road network and bottle-neck cities in India. From the analysis, Koti Women's College in Metropolitan City Hyderabad with 0.41527 and Metropolitan City Hyderabad in India with 0.18956 betweenness centrality leads to narrow junctions. The high betweenness centrality junctions need to be relaxed for easy flow of traffic.

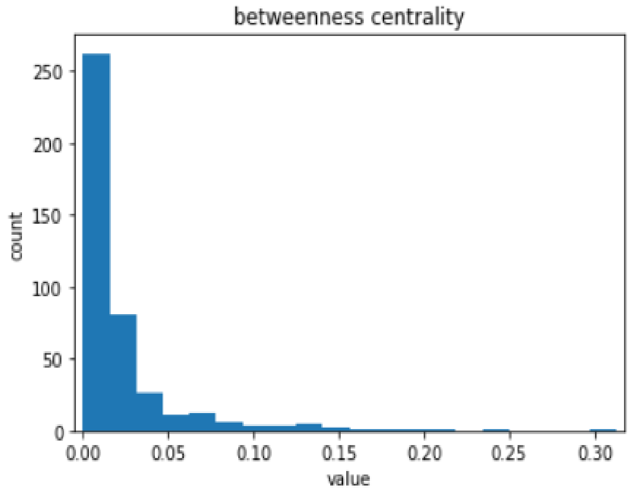

Fig.7.Betweenness centrality distribution over Metropolitan City Hyderabad city road Network

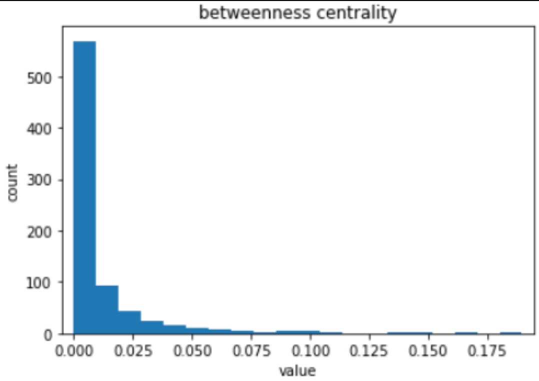

Fig.8. Betweenness centrality distribution over National Highway road Network.

The histogram in Fig. 7 and 8 is used to find the distribution of betweenness centrality among different networks. The nodes with betweenness centrality around 0.02 in Metropolitan City Hyderabad city are more in number. Most nodes range from 0 to 0.15 in Metropolitan City Hyderabad city and 0 to 0.0075 in the National highway road Network. Nodes above 0.10 in Metropolitan City Hyderabad city and 0.125 in the National highway road Network require an immediate relaxation for ease of traffic flow.

3)Edge Betweenness Centrality:

For the Metropolitan City Hyderabad road network, a road connecting two areas in Metropolitan City Hyderabad city with a high centrality value represents a bridge-like connection between two city sections, the elimination of which will impact connectivity among several regions. In the National Highway road network, roads linking two cities with a high centrality will lead to more excellent, effective connectivity between many areas in India.

In (3) terms define the following

For G(C, R) Network,

a=Starting Node.

b=ending Node.

C=Edge in the Network.

EB_c = Edge Betweenness centrality for edge C

.

$$EB_c = \sum_{a \neq b \neq t} \frac{\sigma_{ab}(C)}{\sigma_{ab}} \qquad (3)$$

To understand the calculation of the edge between centrality, from Fig. 4, Consider the Dilsukhnagar-Malakpet edge.

TABLE 6. BETWEENNESS CENTRALITY MEASURE OF EXEMPLARY AREAS

	σ ab	σ ab (c)	$\frac{\sigma_{ab}(C)}{\sigma_{ab}}$
(Nagole, Lb Nagar)	1	0	0
(Nagole, Dilsukhnagar)	1	0	0
(Nagole, Malakpet)	1	1	1
(Lb Nagar, Dilsukhnagar)	1	0	0
(Lb Nagar, Malakpet)	1	1	1
(Lb Nagar, Chaitanyapuri)	1	0	0

(Nagole, Chaitanyapuri)	1	0	0

Table 4.Shows that the centrality of the Dilsukhnagar-Malakpet edge is $\sum \left(\sigma_{ab}(c) / \sigma_{ab} \right) = 2$. Similarly, the edge Between centrality for all the areas of Metropolitan City Hyderabad and the National highway road network in India is calculated.

TABLE 7. EDGE BETWEENNESS CENTRALITY MEASURE

Metropolitan City Hyderabad Road Network			National Highway Road Network		
From	**To**	**Centrality value**	**From**	**To**	**Centrality value**
Koti Women's College	Lakdikap-ool	0.16159	Hyderabad	Kurnool	0.15000
Koti Women's College	Dilsukhn-agar	0.15967	Nagpur	Lakhnadon	0.14148
Afzalgunj	M.Marke-t	0.13080	Nagpur	Hyderabad	0.13969
Afzalgunj	CBS	0.12918	Kurnool	Chikkaballapur	0.13929
Lakdikapo-ol	Nampall-y	0.12816	Bangalore	Chikkaballapur	0.13824
Mehdipat-nam	Lakdikap-ool	0.12753	Lakhnadon	Jhansi	0.12904
Mehdipat-nam	Langer house	0.12370	Delhi	Ambala	0.12837
Golkonda	Langer house	0.12212	Ambala	Jalandhar	0.10540
Ameerpet	Lakdikap-ool	0.11788	Gwalior	Jhansi	0.10305
Tarnaka	Moulali	0.11336	Etawah	Gwalior	0.09953

The Edge betweenness centrality of different roads ranges from 0 to 0.161596 in Metropolitan City Hyderabad and 0 to 0.15 in India. From Table 3, Edge Betweenness Centrality helps in knowing the bottleneck roads, which can be used as a parameter to remove the narrow type of roads. The edge betweenness centrality is highest for Koti Women's college to Lakdikapool road in the Metropolitan City Hyderabad road network Metropolitan City Hyderabad to Kurnool road in India. The centrality can be reduced by constructing more roads between two or more cluster

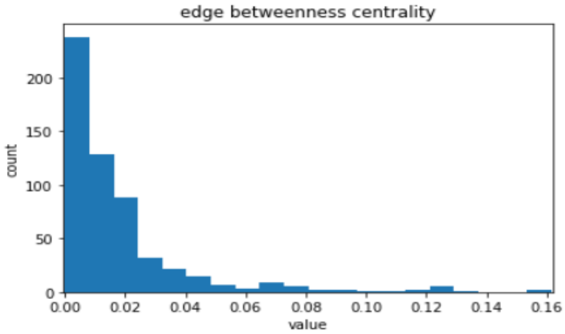

Fig.8. Edge Betweenness centrality distribution over Metropolitan City Hyderabad city road Network

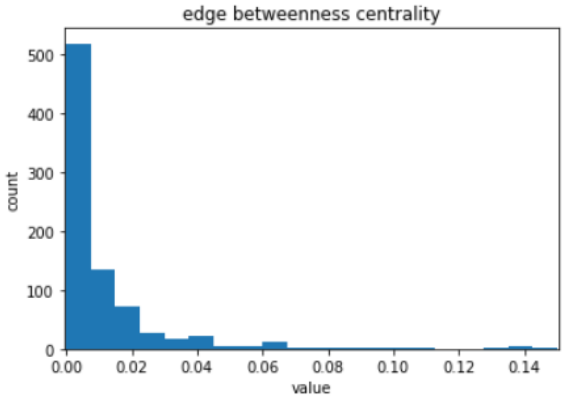

Fig.9.Edge Betweenness centrality distribution over National highway road Network.

The histogram in Fig. 8 and Fig. 9 is used to find the distribution of edge betweenness centrality among the different networks. The edges with edge betweenness centrality around 0.01 in Metropolitan City Hyderabad and road with 0.015 in India are more in number. Edges with centrality measure more than 0.08 in Metropolitan City Hyderabad and 0.06 in the National highway road network have to be relaxed as there is more probability of high traffic congestion.

4)Eigen Vector Centrality:

Eigen Vector centrality represents how a node is influential in the network. The areas connected with high values will have high Eigen Vector centrality. Nodes with the highest Eigenvector centrality are shown in Table 10. To understand the calculation of Eigenvector centrality, From Fig. 4, take the adjacency matrix of each area, multiply adjacency matrix with single column matrix which has all values as one, it is in the form AX=B.

TABLE 8. ADJACENCY MATRIX OF EXEMPLARY AREAS

	Lb Nagar	Chaitanyapuri	Dilsukhnagar	Malakpet	Nagole
Lb Nagar	0	1	0	0	1
Chaitanyapuri	1	0	1	0	1
Dilsukhnagar	0	1	0	1	0
Malakpet	0	0	1	0	0
Nagole	1	1	0	0	0

Iteration one

$$\begin{bmatrix} 0 & 1 & 0 & 0 & 1 \\ 1 & 0 & 1 & 0 & 1 \\ 0 & 1 & 0 & 1 & 0 \\ 0 & 0 & 1 & 0 & 0 \\ 1 & 1 & 0 & 0 & 0 \end{bmatrix} \times \begin{bmatrix} 1 \\ 1 \\ 1 \\ 1 \\ 1 \end{bmatrix} = \begin{bmatrix} 2 \\ 3 \\ 2 \\ 1 \\ 2 \end{bmatrix}$$

Now take the square root of the sum of squares of all values in the B matrix. Divide each value of the B matrix by the square root value and Multiply the updated matrix B with the Adjacency matrix.

Iteration second

$$\begin{bmatrix} 0 & 1 & 0 & 0 & 1 \\ 1 & 0 & 1 & 0 & 1 \\ 0 & 1 & 0 & 1 & 0 \\ 0 & 0 & 1 & 0 & 0 \\ 1 & 1 & 0 & 0 & 0 \end{bmatrix} \times \begin{bmatrix} 0.4264 \\ 0.6396 \\ 0.4264 \\ 0.2132 \\ 0.4264 \end{bmatrix} = \begin{bmatrix} 1.066 \\ 1.2792 \\ 0.8528 \\ 0.4264 \\ 1.066 \end{bmatrix}$$

Repeat the same process for N-1(here 4) iterations.

Iteration five

$$\begin{bmatrix} 0 & 1 & 0 & 0 & 1 \\ 1 & 0 & 1 & 0 & 1 \\ 0 & 1 & 0 & 1 & 0 \\ 0 & 0 & 1 & 0 & 0 \\ 1 & 1 & 0 & 0 & 0 \end{bmatrix} \times \begin{bmatrix} 0.4833 \\ 0.6151 \\ 0.3515 \\ 0.1757 \\ 0.4833 \end{bmatrix} = \begin{bmatrix} 1.0984 \\ 1.3181 \\ 0.7908 \\ 0.3515 \\ 1.0984 \end{bmatrix}$$

After dividing each value in matrix B, we get eigenvector centrality for each area as

TABLE 9. EIGEN VECTOR CENTRALITY OF EXEMPLARY AREAS

Area	Eigen vector centrality
Lb Nagar	0.4962
Chaitanyapuri	0.5955
Dilsukhnagar	0.3572
Malakpet	0.1588
Nagole	0.4962

TABLE 10. EIGEN VECTOR CENTRALITY MEASURE

Metropolitan City Hyderabad Road Network		**National Highway Road Network**	
Areas	**Centrality values**	**Cities**	**Centrality values**
Koti Women's College	1.0	Jhansi	0.42497
AfzalGunj	0.93571	Jabalpur	0.30077
Charminar	0.90795	Allahabad	0.23872
Lakdikapul	0.64685	Lakhnadon	0.23377
CBS	0.63492	Gwalior	0.22584
Mehdipatnam	0.52897	Chhatarpur	0.22455
Dilsukhnagar	0.42759	Shivpuri	0.22378
Nilofer	0.41316	Rewa	0.21164
Bela	0.38158	Varanasi	0.20778
Kachiguda	0.377097	Banda	0.19730

This Analysis of the Metropolitan City Hyderabad road Network can further help establish hospitals or emergency services at places with high eigenvector centrality values. Koti Women's College in the Metropolitan City Hyderabad road network is a more influential area, so setting up public services will be more significant to the public. It helps in the easy flow of people because of setting public services in an influential area.

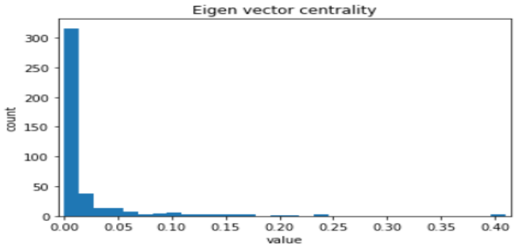

Fig.10. Eigen Vector centrality distribution over Metropolitan City Hyderabad city road Network

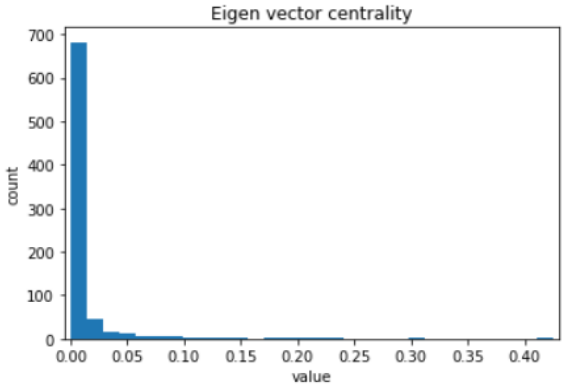

Fig.11. Eigen Vector centrality distribution over National highway road Network

The histogram in Fig. 10 and Fig. 11 is used to find the distribution of eigenvector centrality among the network. The nodes with eigenvector centrality around 0.005 in the National highway road Network and 0.01 in Metropolitan City Hyderabad Network are more in number. Eigen Vector centrality above 0.10 in Metropolitan City Hyderabad city and National highway Road Network has to be considered more influential nodes.

C. Conclusion and Future work

This work takes the road network of Metropolitan City Hyderabad city and the National highways of India, which is further analyzed with various centrality measures. These different centralities can be used in many ways. The analysis leads us to various centrality distributions, which can be used further and help in solving bottle-neck junctions and roads in a city. This analysis also helps in knowing the connectivity, influence over other nodes, and the closeness of the nodes. This work helps in understanding the importance of a node on different networks.

Real-time data, which changes every minute, is helpful for this study for more exact analysis. Analysis of this real-time data can help solve many more problems in society. Many other centrality measures can be applied to the networks for efficiently evaluating the network. Different parameters of a road network can be taken to solve many problems.

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