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Investigation of Performance Indicator for Public Transit Connectivity in Multi-Modal Transportation Network of NCT Delhi

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Abstract: Centrality plays a crucial role as agencies at the federal and state level focus on expanding the public transit system to meet the demands of a multimodal transportation system. Transit agencies have a need to explore mechanisms to improve connectivity by improving transit service. This requires a systemic approach to develop measures that can prioritize the allocation of funding to locations that provide greater connectivity, or in some cases direct funding towards underperforming areas. The concept of centrality is well documented in social network literature and to some extent, transportation engineering literature. However, centrality measures have limited capability to analyze multi-modal public transportation systems which are much more complex in nature than highway networks. In my study area, we propose measures to determine Network centrality from a QGIS SOFTWARE which is based on graph theoretic approach for all levels of transit service coverage integrating routes, schedules, socioeconomic, demographic and spatial activity patterns. The objective of using Network centrality as an indicator is to quantify and evaluate transit service in terms of prioritizing transit locations for funding; providing service delivery strategies, especially for areas with large multi-jurisdictional, multi-modal transit networks; providing an indicator of multi-level transit capacity for planning purposes; assessing the effectiveness and efficiency for node/stop prioritization; and making a user friendly tool to determine locations with highest connectivity while choosing transit as a mode of travel. The proposed analysis offers reliable indicators that can be used as tools for determining the transit connectivity of a multimodal transportation network.

Keyword: Network centrality, multimodal transit network, public transportation.

I. INTRODUCTION

Transit networks consist of nodes and lines to represent their layout. The nodes are called stops and the lines are called links or route segments. Links in a multimodal transit network have different characteristics from those in a road network. While link in a road network is a physical segment that connects one node to another, link of a multi-modal transit network is part of transit line that serves a sequence of transit stops (nodes). Since a stop can be served by different transit lines, multiple transit links may exist between nodes in a multi-modal transit network. But in the case of a highway network only one link exists between two nodes. . Headway, frequency, speed, and capacity are critical terms that define the characteristics of a route for a transit link. Similarly, transit nodes are composed of a different set of characteristics than highway nodes. The nodes and links of the transit system are synonymous with the analysis of connectivity in graph theory (Harary, 1971). The structure of the public transit network is critical in determining performance, coverage, and service of the network. Network centrality can be used as a measure to study the performance of the transit system which will assist decision makers in prioritizing transit investment and deciding which stops/zone need immediate attention in regard to operation and maintenance (Hadas and Ceder, 2010). In this context, centrality is one of the index measures that can be used to quantify and evaluate transit performance (Borgatti, 2005). Measures of transit connectivity can be used for a number of purposes. First, in a public or quasi-public agency, connectivity can be used as a measure in public spending to quantify transit stop and route performance and to evaluate the overall system performance. Second, in a rural or suburban area where exact information on transit ridership, boardings, and alightings are not available (which are generally obtained from a comprehensive and well-designed transit assignment in a travel demand model or from an advanced transit system where smart cards are used to keep track of revenues) to obtain a measure of performance for developing service delivery strategies.

Third, to serve as a performance measure in a large scale urban multi-modal transit network containing local buses, express buses, metro, local light rail, regional light rail, bus rapid transit, and other transit services which serve both urban and rural areas, where transit services are provided by different public and private agencies with little coordination . Fourth, to provide an assessment of effectiveness and efficiency of a transit system with quantifiable measures that can be used to prioritize the nodes/zone in a transit system, particularly in terms of emergency evacuation. Fifth, to assist transit agencies with the development of a set of tools for the potential transit users to assess the level and quality of transit service at their place of residence or work.

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This paper proposes a unique approach to measuring transit connectivity, particularly for applications where the use of transit assignment models or ridership tracking tools is not available. This method incorporates a Network centrality and distance to nearest hub based on (QGIS) to determine the performance of large-scale multimodal transit networks to quantify the measures of connectivity of node/zone. This is achieved through an assessment of centrality that incorporates unique qualities of each node in the network and measures of accessibility.

Network centrality is a performance indicator in this paper, the tools v.net. centrality in QGIS are used to find centrality indexes which is the combination of four indexes degree centrality, closeness centrality, betweeness centrality and eigen vector centrality and distance to nearest hub tools are used to find the node/zone connectivity of Delhi.

II. LITERATURE REVIEW

Centrality measures are well studied in the literature. However, their application to public transit is rare. Table 1 represents a summary of connectivity index measures (or derivatives thereof) found in the literature. The first measure in Table 1 is degree of centrality. The total number of direct connections a node has to other system nodes is defined as the degree centrality. Eq. (1) suggest that the degree of centrality of a node $D_c(n)$ in a larger network ''N'' is the sum of the number of links originated from ''p'' number of nodes crosses through node ''n'' (δ_{np}), where p represents all nodes except n (i.e. p e (N n)). This measure is then normalized by dividing by the total number of system nodes N minus 1. Eq. (2) represents a conditional statement to support the degree centrality, where δ_{np} represents a binary indicator variable which takes the value 1, if node ''p'' is incident upon node ''n'', and 0 otherwise. Degree centrality is the most widely used measure of connectivity in the literature which ranges from transportation to computer science to epidemiology (Martínez et al., 2003; Liu et al., 2005; Bell et al., 1999; Junker et al., 2006; Guimerà et al., 2005).

The degree centrality $D_c(n)$ simply counts the number of direct connections a node has to other nodes in the network, but does not account for the quality of the connection or indirect accessibility to other nodes. Eigenvector centrality acknowledges that not all connections are equal. It assigns relative 'scores' to all nodes in the network based on the principle that connections to high-scoring nodes contribute more to the score of the node in question than equal connections to low-scoring nodes. The eigenvector centrality De(n) of node n, in the network N (n,l), is defined in Eq. (3), which is the multiplication of degree centrality to δ_{np}, and scaled by the eigenvalue k. Degree centrality ($D_c(n)$) is the eigenvector in Eq. (3). The eigenvector centrality succeeded the development of degree centrality and is used for a number of studies.

Table 1
Literature on centrality and connectivity measures in social networks and transportation.

Measure	Mathematical construct	Eq. no.	Definition	Application
Node-measure: degree centrality	$D_c(n) = \frac{\sum_{p \in N} \delta_{np}}{n-1}$, where, $\delta_{np} = \begin{cases} 1 \text{ if } p \text{ is dependent on} & n, \forall p \in (N-n) \\ 0 & \text{otherwise} \end{cases}$	(1) (2)	Normalized score based on total number of direct connections to other network nodes	***Network and Graph Theory*** (Borgatti, 2005; Freeman, 1978; Latora and Marchiori, 2007; Costenbader and Valente, 2003; Martínez et al., 2003); ***computer and information science*** (Liu et al., 2005; White, 2003; Bell et al., 1999; Bader and Madduri, 2006); gene-disease (Özgür et al., 2008; Junker et al., 2006; Aittokallio and Schwikowski, 2006); shortest path (Borgatti, 2005; Opsahl et al., 2010; Ahmed et al., 2006); ***transportation*** (Jiang and Claramunt, 2004; Guimerà et al., 2005; Derrible and Kennedy, 2009)
Node-measure: eigenvector centrality	$D_e = \frac{\sum_{p \in N} \delta_{np} \times D_c(n)}{\lambda}$	(3)	Assigns relative 'scores' to all nodes in the network based on the principle on connections	***Network and Graph Theory*** (Bonacich, 2007; Bonacich and Lloyd, 2001; Ruhnau, 2000); ***Social Science*** (Ahmed et al., 2006; Estrada and Rodríguez-Velázquez, 2005; Newman, 2004; Garroway et al., 2008; Moore et al., 2003; Carrington et al., 2005)
Node-measure: closeness centrality	$D_{cc}(n) = \frac{\sum_{n_1 \in N} L_{n,n_1}}{N-1}, \forall N > 2$	(4)	Sum of graph-theoretic distances from all other nodes	***Network and Graph Theory; Shortest path*** (Ahmed et al., 2006; Leydesdorff 2007; Crucitti et al., 2006); ***Computer science*** (Otte and Rousseau, 2002; Liu et al., 2005; Bell et al., 1999)

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Node-measure: betweeness centrality	$D_b(n) = \sum_{n_1} \sum_{n_2} \frac{\delta_{n-1n_2}(n)}{\delta_{n_1,n_2}}, n_1 \neq n \neq N_2$	(5)	Sum of the number of geodesic paths that pass through a node *n*	***Network and Graph Theory*** (Otte and Rousseau, 2002; Newman, 2005; White ar Borgatti, 1994; Crucitti et al., 2006); ***computer and information science*** (Liu et al., 2005; Bell et al., 1999; Barthlemy, 2004; Goh et al., 2003); shortest path (Ahmed et al., 2006; Brandes, 2001)
Node-measure: connectivity index	$\theta_n = \sum_{i \in L} P^t_{i,n} \mu_{l,n}$	(6)	Sum of connecting powers all lines crossing through a node *n*	***Transportation*** (Lam and Schuler, 1982; Hadas and Ceder, 2010; Yang et al., 2007; Scott et al., 2006; Park and Kang, 2011) ***Network and Graph Theory*** (Caporossi et al., 1999; Randic 2001; Caporossi et al., 2003; Araujo and de la Peña, 1998; Gauthier, 1968; Frank et al., 2006)
Node-measure: transfer center (cluster): connectivity index	$\theta_\omega = \frac{1}{\lvert S_\omega \rvert - 1} \sum_{n_1 \in S_\omega} \sum_{n \in S_{\omega, n_1 \neq n}} \theta_n \rho_{n_1,n}$	(7)	Sum of connecting powers all lines crossing through a transfer center	***Transportation and Other applications*** (Ahmed et al., 2006; Leydesdorff, 2007; Pai and Kang, 2011; Basak et al., 1994;Sabljic and Horvatic, 1993; Hilgetag and Kaiser, 2004; Sun and Danzer, 1996)
Node-measure: region connectivity index	$\theta_R = \frac{1}{\lvert S_\sigma \rvert - 1} \sum_{n \in S_R} \theta_n$	(8)	Sum of connecting powers all nodes in a region	***Transportation and Other applications*** (Ahmed et al., 2006; Leydesdorff, 2007; White and Borgatti, 1994; Crucitti et al., 2006; Yang et al., 2007; Park and Kang, 2011)
Line-measure: connecting power	$P^t_{i,n} = \frac{P^o_{l,n} + P^i_{l,n}}{2}$	(9)	Connectivity power of a line which is a function of transit characteristics	***Transportation and Other applications*** (Ahmed et al., 2006; Leydesdorff, 2007; Yang et al., 2007; Park and Kang, 2011)
Line-measure: connectivity index	$\theta_l = \frac{1}{\lvert S_l \rvert - 1} \sum_{n \in S_l, n \neq n_0} \theta_n$	(10)	Sum of connecting powers all nodes in a line	***Transportation and Other applications*** (Ahmed et al., 2006; Leydesdorff, 2007; White and Borgatti, 1994; Crucitti et al., 2006; Park and Kang, 2011)

As defined by Freeman (1978), a node's closeness centrality is the sum of graph-theoretic distances from all other nodes, where the distance from a node to another is defined as the length (in links) of the shortest path from one to the other. Eq. (4) shows the formulation for closeness centrality. Nodes with low closeness scores have short distances from others, and will tend to be more accessible. In topology and related areas in mathematics, closeness is one of the basic concepts in a topological space.
Betweenness centrality is defined as the share of times that a node n1 needs a node n (whose centrality is being measured) in order to reach a node n2 via the shortest path. Eq. (5) shows the formulation for betweenness centrality. Alternatively, betweenness centrality basically counts the number of geodesic paths that pass through a node n. The denominator exists to address the case where there are multiple geodesics between n1 and n2, and node n is only along some of them. Hence, betweenness is essentially n's share of all paths between pairs that utilize node n—the exclusivity of n's position.
Previous node indexes did not take into account transit characteristics. Park and Kang (2011) introduced the transit characteristics into the node centrality measures and proposed the connectivity index as a true measure of a transit node. The connectivity index of a node can be defined as the sum of connecting powers1 of all lines crossing through a node n. The connectivity index is shown in Eq. (6). The total connecting power of a node is the multiple of connecting power of a line at node n ($P^t_{l,n}$). The conditional value of presence of a line is represented by a binary indicator variable ($\mu_{l,n}$), which takes the value 1 if line l contributes to the connectivity at node n, and 0 otherwise. The characteristics of a link contain the performance of a series of nodes in that link. A link is a part of the transit route, which in turn is a function of the speed, distance, frequency, headway, capacity, acceleration, deceleration, and other factors. Since a route will contain both in-bound and out-bound, the line performance will in part depend upon the directionality of the transit route, that is, whether the line is circular or bidirectional.
The total connecting power of line l at node n is the average of outbound and inbound connecting power and can be defined as-

$$P^t_{l,n} = \frac{P^o_{l,n} + P^i_{l,n}}{2} \tag{6.1}$$

The outbound connecting power of a line *l*, at node *n* can be defined as (Park and Kang, 2011)

$$P^o_{l,n} = \alpha\left(C_l \times \frac{60}{F_l} \times H_l\right) \times \beta V_l \times \gamma D^o_{l,n} \tag{6.2}$$

here C_l is the average vehicle capacity of line l, Fl is the frequency on line l (60 is divided by Fl to determine the number of operation per hour), H is the daily hours of operation of line l, V_l is the speed of line l, and $D^o_{l,n}$ is the distance of line l from node n to the destination. The parameter α is the scaling factor coefficient for capacity which is the reciprocal of the average capacity of the system multiplied by the average number of daily operations of each line, β is the scaling factor coefficient for speed represented by the reciprocal of the average speed on each line, and ɤ is the scaling factor coefficient for distance which is the reciprocal of the average network route distance. Similarly, the inbound connecting power of line l can be defined as-

$$P^i_{l.n} = \alpha\left(C_l \times \frac{60}{F_l} \times H_l\right) \times \beta V_l \times \gamma D^i_{l,n}$$

6.3

Where, $P^i_{l,n}$ is the inbound connecting power of line l at node n. While the outbound connecting power of a transit line at a certain transit stop represents connectivity from the stop to the downstream stops of the transit line, the inbound connecting power measures connectivity from the upstream stops of the transit line to the stop under consideration. Analyzing connectivity of transfer centers is critical to exploring the performance of a combination of several transit stops through which passengers change their mode of transportation. Level of service is one of the critical measures that determine the performance of the transfer center. Eq. (7) represents the connectivity index of a transfer center. Where $\rho_{n1,n}$ is the passenger acceptance rate and is defined as

$$\rho_{n_1,n} = a \times exp^{-bt_{n_1,n}}$$

7.1

Where, a and b are the parameters of passenger acceptance rate, and $t_{n1,n}$ is the transfer time to travel from node n1 to n. The parameters for a and b are assumed from Kim and Kwon (2005) and estimated based on model estimation which found that walk time provided an R-square value of .9846; that is, walk time alone explained 98.46 percent of the passenger transfer acceptance rates.

Similarly, the connectivity index of a region (Eq. (8)) can be defined as the sum of connectivity indexes of all nodes and scaled by the density measure, where ρ_R is a density measure of region R. The density could be a measure in population, employment, and household in the region. The line connecting power and connectivity indexes are shown in Eqs. (9) and (10).

S. Mishra et al [2012] , we propose measures to determine connectivity from a graph theoretical approach for all levels of transit service coverage integrating routes, schedules, socioeconomic, demographic and spatial activity patterns. The objective of using connectivity as an indicator is to quantify and evaluate transit service in terms of prioritizing transit locations for funding; providing service delivery strategies, especially for areas with large multi-jurisdictional, multi-modal transit networks; providing an indicator of multi-level transit capacity for planning purposes; assessing the effectiveness and efficiency for node/stop prioritization; and making a user friendly tool to determine locations with highest connectivity while choosing transit as a mode of travel.

S. Mishra et al [2015], Agencies at the federal, state and local level are aiming to enhance the public transportation system (PTS) as one alternative to alleviate congestion and to cater to the needs of captive riders. To effectively act as a viable alternative transportation mode, the system must be highly efficient.

Sarker, A. A., Welch, T. F., Golias, M. M., & Kumar, A. [2017], This research develops and recommends an advanced and practical method to better evaluate and improve the equity and accessibility of public transit for people. In such sense, the transit gap index (TGI) is developed by taking demographic features, spatial and temporal transit service characteristics into consideration. A case study in the City of Charlotte is conducted and the associating comprehensive gap analysis based on the proposed methodology is provided. This research also develops guidelines and recommends best practices for the use of GTFS data as a main data source to better understand and assess public transit equity and accessibility for public transportation planning an operation.

H Liu and Y Tong [2020], Transportation recommendation is one important map service in navigation applications. Previous transportation recommendation solutions fail to deliver satisfactory user experience because their recommendations only consider routes in one transportation mode (uni-modal, e.g., taxi, bus, cycle) and largely overlook situational context.

III. OBJECTIVES

Objectives of the present studies are-

1) To investigate Network centrality based on graph centric approach for all levels of transit service coverage integrating routes, schedules, socio-economic, demographic and spatial activity patterns.
2) To compute connectivity indicators to represent the potential ability of a bus and metro transit system to serve residents in National Capital Territory (NCT), Delhi.
3) To identify the Zones/regions having the lesser transit connectivity as quantified using connectivity indications.

Measuring transit system performance and the level of service at many different levels is vital to funding decisions (Dajani and Gilbert, 1978). Agencies with the objective to improve the transit system using external funds must make the case that the project will be a worthwhile improvement to the system. At the same time, agencies interested in investigating the potential effect of removing a stop, group of stops or transit line from service must know the potential effect it will have on the performance of the system. In the absence of complex transportation demand models, this information is nearly impossible to obtain (Baughan et al., 2009). A methodology that reduces the need for large amounts of data, yet provides important information on system performance is critical to the decision making process. Transit planning agencies may also be interested in applying such an index to determine the best use of land surrounding well connected transit nodes. Beyond Transit Oriented Development (TOD) style plans, the connectivity index provides a way for planners to measure passenger acceptance rates and accessibility for a single node based on its access within an entire multi-modal regional transportation network.

The objectives of this paper are several fold, with the overall goal of providing a strong measure of system performance with the lowest possible data requirements. This paper will first seek to construct a list of node and link based commonly encountered flow processes and define them in terms of a few underlying characteristics; second, to determine and propose the best suited measures in terms of transit connectivity; third, to examine these measures by running simulations of flow processes and comparing the results in a real world case study; and fourth, to suggest the best practices which can be adopted for decision making. All the aforementioned problems require the development of a tool to quantify connectivity of a public transportation system. The proposed methodology is presented in the next section-

IV. METHODOLOGY

The methodology presented in this paper is based on network centrality and distance to nearest hub tools in QGIS, which determined the connectivity of study area zone. The method describe below in details are-

A. Network Centrality

Network centrality is a parameter which I used for the investigation of connectivity of multimodal transit network. Network centrality defined the centrality of network which is based on the GRAPH THEORY. In graph theory the relationship is analyzed through topology which is concerned with the position and relationship between points and lines and areas. When graph theory is applied, the transport network may be visualized as a set of vertices (intersections, cities, towns, terminals, etc) which are connected by a set of links called edges (roads and railroads).

Network centrality is defined as centrality index which are discussed below-

- *Degree Centrality:* Degree centrality is defined as the direct connection of node/stop. if a node is connected to 4 node then their degree of node is 4. The node which has more degree centrality is a hub center for a network.
- *Betweeness Centrality:* It is basically the number of shortest path passes through the node. The node which has more betweeness centrality means from that node maximum no of shortest path passes from one node to other node.
- *Closeness Centrality:* Closeness centrality basically define the closeness of node to the other node in the network, and also closeness to the hub center.
- *Eigen Vector Centrality:* It defined the node which are more connected to the nearest important center. More the eigen vector centrality more is the node connection from hub center.

The above four centrality indexes discuss is based on graph theory which is calculated by QGIS, which discussed in details below-

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1) *V.net.centrality:* The Tools which are used for determining the centrality index is **v.net. centrality** **,**which are the processing tool in QGIS shown below in figure4.1 v.net.centrality tool are used to compute degree, betweeness, closeness and eigen vector centrality measure in the network.

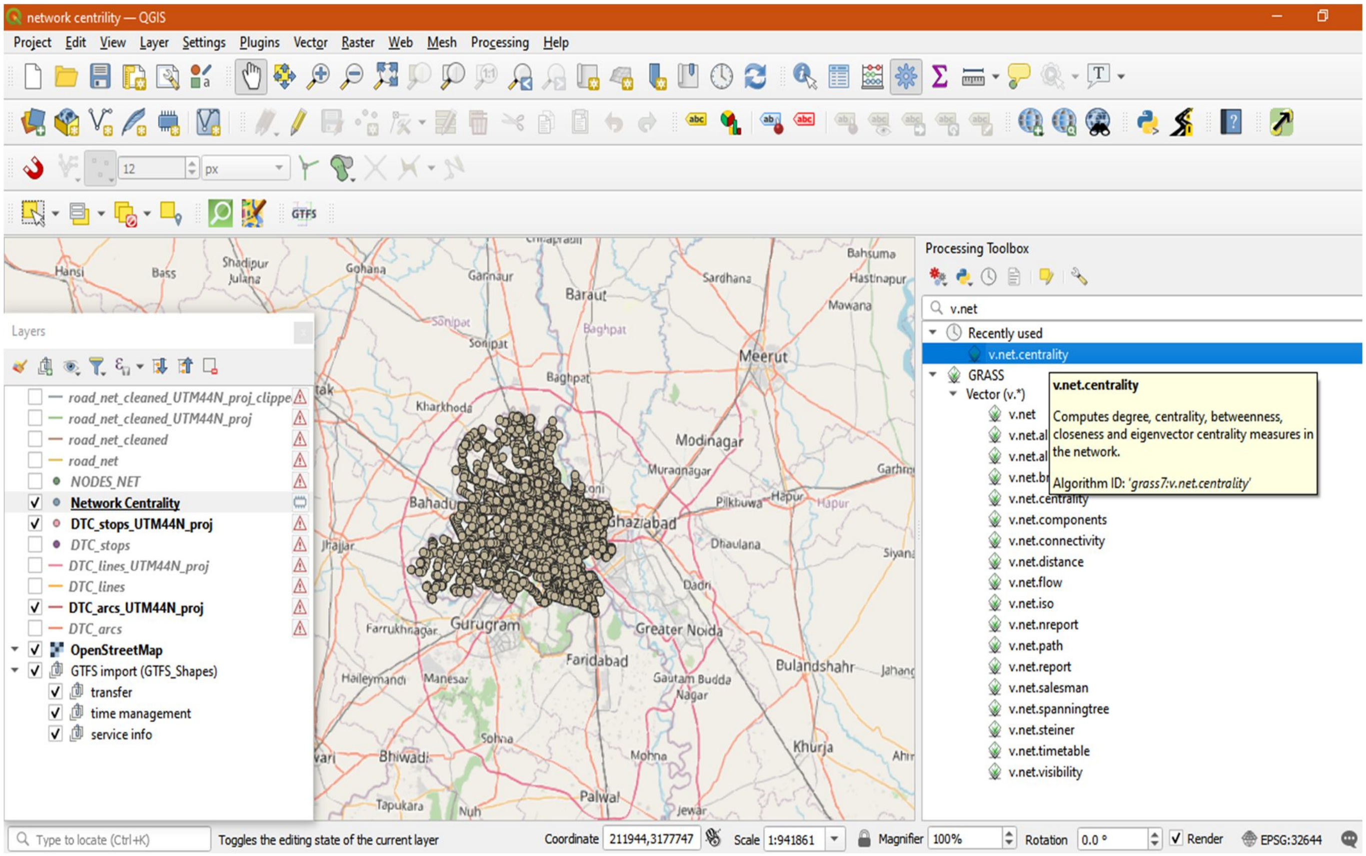

Figure 4.1 v.net.centrality processing tool [QGIS]

B. Distance to Nearest Hub

Distance to nearest hub is a processing tool in QGIS to compute the distance of nearest hub for each stops/line in the network. In this paper hub is transfer point/center .transfer center is the center which transfer the traffic from origin to destination. Example – Delhi metro behave as a transfer point which transfer the traffic from origin to destination shown below in figure4.2-

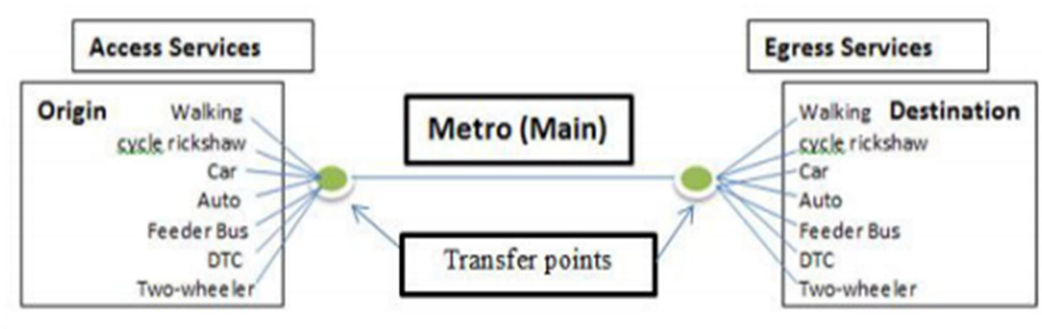

Figure 4.2 Transfer point between origin and destination

In the above figure4.2 origin is DTC bus and metro is transfer point which transfer the traffic from origin to destination in this paper calculate the distance of nearest transfer point from DTC bus network for each zone of Delhi, which gives the connectivity of bus and metro network in each zone of Delhi.

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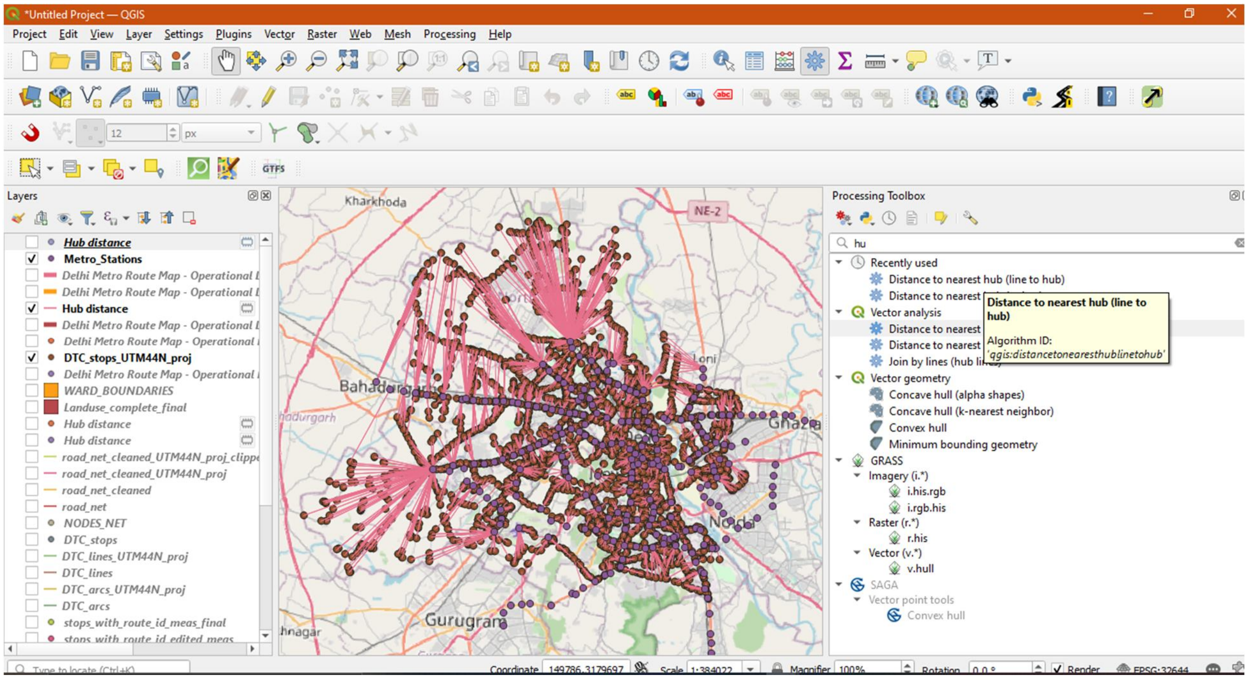

Figure4.3 Distance to nearest hub processing tool (QGIS)

In the above figure4.3 distance to nearest hub processing tool are used to find nearest hub from origin to reach the destination. In this paper two tools are used first is network centrality and second is distance to nearest hub in QGIS which are combined together to find the zonal connectivity of network.

V. CASE STUDY

The proposed methodology is applied to the multimodal transit network of NCT Delhi. In this study the connectivity of Delhi is divided in to zone-wise means zonal connectivity of Delhi. The zone wise classification of Delhi is shown below-

Figure5.1 Zonal classification map view of Delhi

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Delhi is classified in to several zone which are given below-

- New Delhi Zone
- Central zone
- North zone
- North west zone
- West zone
- South west zone
- South zone
- South east zone
- East zone
- North zone

We select the DTC stops/line from each zone which has highest centrality index and compare these data from each zone and also compare the distance to nearest hub (Transfer center) from these selected bus stops and finally we find the connectivity of each zone of Delhi on the basis of centrality indexes and nearest distances from hub.

A. DTC Bus Network

The Delhi Bus data is made public according to GTFS. GTFS defines common format for public transportation schedules and associated geographic information.

1) Static Data

The static timetable of Delhi Buses can be accessed using the following files:

a) agency.txt
b) calendar.txt
c) stops.txt
d) routes.txt
e) trips.txt
f) stop_times.txt

Dynamic/real time data-It can be access through GOOGLE API KEY

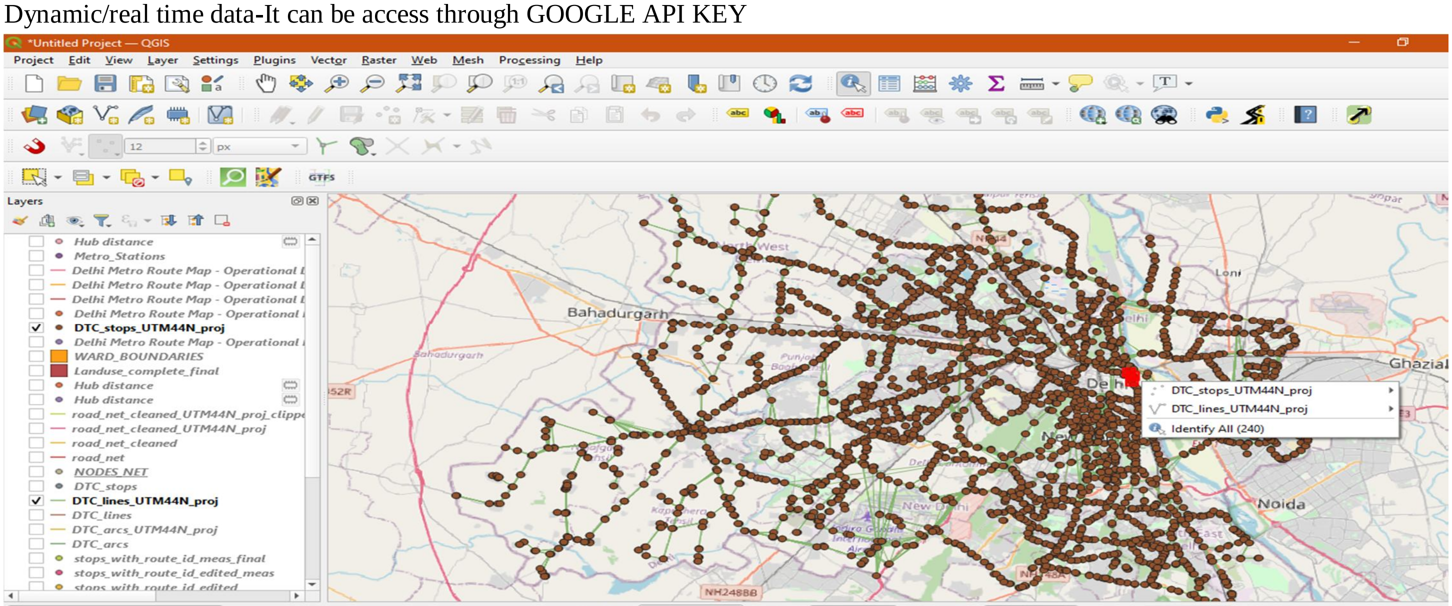

Figure5.2 DTC STOPS AND ROUTE NETWORK DATA SET[QGIS]

In the above figure5.2 the Digitized dataset of DTC bus stop and DTC bus route details are shown which can be extracted from GTFS data by using plugins GTFS IMPORT/GTFS LOADER.

B. Delhi Metro Network

1) Delhi metro data is a static data which is available in DMRC official site

2) Delhi metro behave as a Transfer center which transfer the traffic from origin to destination.

3) Delhi metro is divided in three operational phase

-operational phase 1(65.11km)

-operational phase 2(124.93)

-operational phase 3(165.23)

Delhi metro behave as a transfer center which transfer the traffic from origin to destination. In this paper origin is DTC bus stops and Delhi metro is transfer center. The distance to nearest hub is calculated for bus stops in each zone and here hub is transfer center.

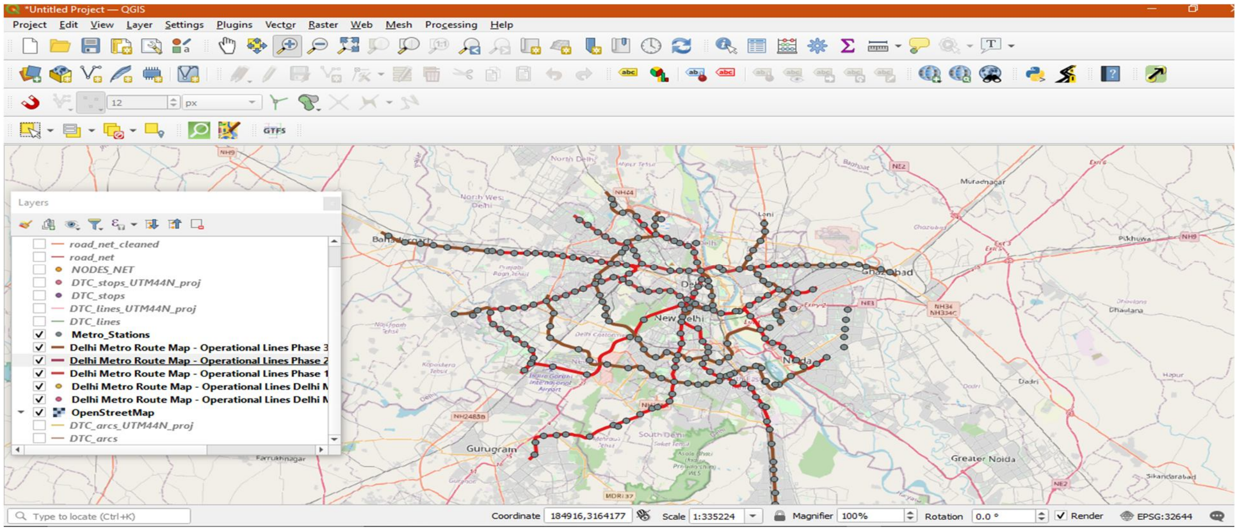

Figure5.3 Delhi metro Route operational phase line[QGIS]

VI. RESULTS

The results reported in this section are based on the methodology which are discussed above in details for the NCT Delhi multimodal transit network. In this paper two tools are used in QGIS to achieve objectives of this paper these two tools are used for the development of zonal connectivity of Delhi.

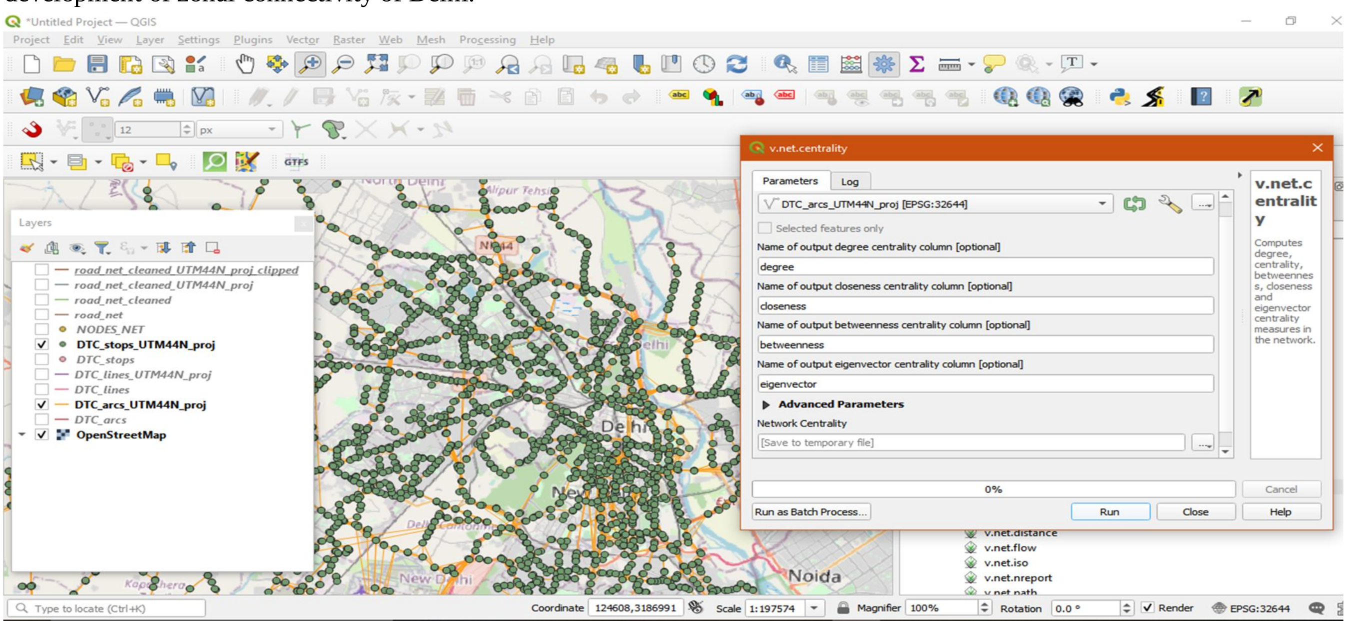

Figure6.1 v.net.centrality processing tool for DTC bus centrality(QGIS)

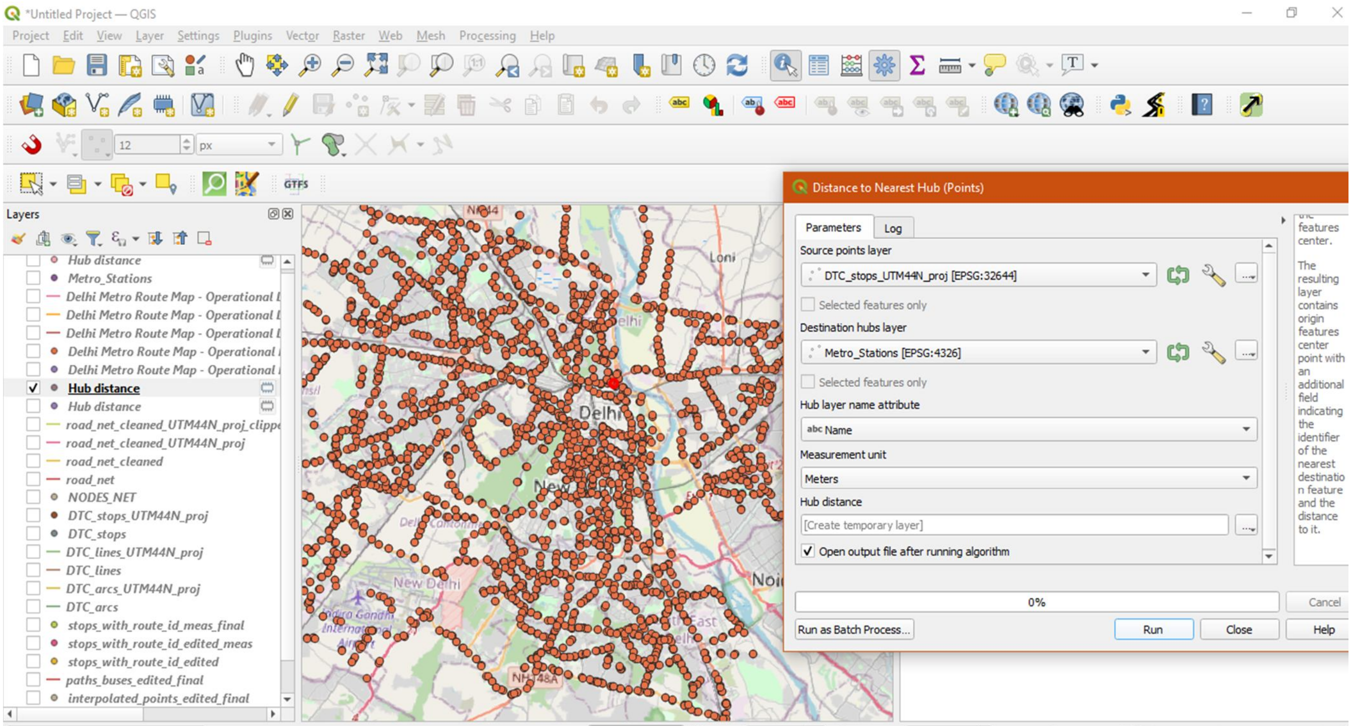

Figure6.2 Distance to nearest hub, source point layer and destination hub layer(QGIS)

In the above figure 6.1 v.net.centrality tool are used to compute the DTC bus network centrality in four index (degree, closeness, betweeness and eigen vector) which are shown in four column of attribute table6.1 below-

In the above figure6.2 distance to nearest hub is used to compute the distance of source point layer i.e DTC Bus to destination hub layer i.e transfer point(Delhi metro).which are shown in attribute table 6.2 below-

Network Centrality — Features Total: 4161, Filtered: 4161, Selected: 0

	fid	cat	degree	closeness	betweenness	eigenvector
1	2686	9325	0.002163	22024.857528	30454	0
2	2687	9326	0.000961	21604.987444	12076	0
3	2684	9323	0.000481	23231.097343	494	0
4	2685	9324	0.000961	22346.238183	19738	0
5	2682	9321	0.000961	15893.760432	58399	0
6	2683	9322	0.000961	21898.440518	2715	0
7	2680	9319	0.001923	15696.156927	17473	0
8	2681	9320	0.000721	15592.963258	0	0
9	1414	8053	0.000721	17055.528829	94128	0
10	1415	8054	0.000481	16466.129005	0	0
11	1412	8051	0.001202	17316.792348	15943	0
12	1413	8052	0.000721	17138.259657	91778	0
13	1410	8049	0.000481	19979.755537	129564	1e-06
14	1411	8050	0.000961	17302.137788	2251	0
15	1408	8047	0.000481	19194.7035	209711	7e-06
16	1409	8048	0.000721	19504.538919	213708	0
17	1422	8061	0.000721	14668.638493	381854	0
18	1423	8062	0.000961	14571.764723	386386	0
19	1420	8059	0.001202	15573.491462	6857	0
20	1421	8060	0.000721	15571.489889	0	0
21	1418	8057	0.001442	14544.56885	313024	0

Show All Features

Table6.1 Network centrality attribute table

Hub distance — Features Total: 4161, Filtered: 4161, Selected: 0

	ident	name	int_tot	out_tot	in_mon-fri	out_mon-fr	in_sat	out_sat	in_sun	out_sun	HubName	HubDist
101	487	Mall Road	2960.370572207...	2960.370572207...	2967.091603053...	2967.091603053...	2941.884615384...	2941.884615384...	2945.283018867...	2945.283018867...	Vishwa Vidalay...	393.4208574478...
102	488	CRPF Camp / C...	552.8174386920...	552.8174386920...	554.0725190839...	554.0725190839...	549.3653846153...	549.3653846153...	550.0000000000...	550.0000000000...	Sarita Vihar Stat...	1555.392954899...
103	485	Darya Ganj	1323.727520435...	1323.727520435...	1326.732824427...	1326.732824427...	1315.461538461...	1315.461538461...	1316.981132075...	1316.981132075...	Delhi Gate Stati...	511.47629567264
104	486	Exchange Store...	1435.618528610...	1435.618528610...	1438.877862595...	1438.877862595...	1426.653846153...	1426.653846153...	1428.301886792...	1428.301886792...	Civil Lines Station	23.68740239786...
105	499	KharKhari Rondh	75.85831062670...	75.85831062670...	76.03053435114...	76.03053435114...	75.38461538461...	75.38461538461...	75.47169811320...	75.47169811320...	Najafgarh Station	7175.510853002...
106	500	Mohan Garden	1449.841961852...	1449.841961852...	1453.133587786...	1453.133587786...	1440.788461538...	1440.788461538...	1442.452830188...	1442.452830188...	Nawada Station	411.881700839519
107	497	PS Tughlaq Road	828.7520435967...	828.7520435967...	830.6335877862...	830.6335877862...	823.5769230769...	823.5769230769...	824.5283018867...	824.5283018867...	Lok Kalyan Mar...	261.2007606273...
108	498	Telephone Exch...	959.6076294277...	959.6076294277...	961.7862595419...	961.7862595419...	953.6153846153...	953.6153846153...	954.7169811320...	954.7169811320...	Rajendra Place ...	384.1552584219...
109	495	Dariyapur Gaon	275.9346049046...	275.9346049046...	276.5610687022...	276.5610687022...	274.2115384615...	274.2115384615...	274.5283018867...	274.5283018867...	Rithala Station	13977.36353125...
110	496	East Patel Nagar	564.1961852861...	564.1961852861...	565.4770992366...	565.4770992366...	560.6730769230...	560.6730769230...	561.3207547169...	561.3207547169...	Rajendra Place ...	442.9092226429...
111	493	Pandav Nagar	1501.046321525...	1501.046321525...	1504.454198473...	1504.454198473...	1491.673076923...	1491.673076923...	1493.396226415...	1493.396226415...	Shadipur Station	480.8472885396...
112	494	ISBT Kashmere ...	654.2779291553...	654.2779291553...	655.7633587786...	655.7633587786...	650.1923076923...	650.1923076923...	650.9433962264...	650.9433962264...	Kashmere Gate ...	114.0067884953...
113	473	Railway Colony...	1630.953678474...	1630.953678474...	1634.656488549...	1634.656488549...	1620.769230769...	1620.769230769...	1622.641509433...	1622.641509433...	Ridge Ramp	1257.605103972...
114	474	11 Murti	1295.280653950...	1295.280653950...	1298.221374045...	1298.221374045...	1287.192307692...	1287.192307692...	1288.679245283...	1288.679245283...	Ridge Ramp	1623.401124882...
115	471	Faiz Road	334.7247956403...	334.7247956403...	335.4847328244...	335.4847328244...	332.6346153846...	332.6346153846...	333.0188679245...	333.0188679245...	Jhandewalan St...	435.8910805940...
116	472	APS Colony/ Jh...	1065.809264305...	1065.809264305...	1068.229007633...	1068.229007633...	1059.153846153...	1059.153846153...	1060.377358490...	1060.377358490...	Shankar Vihar S...	2112.873592100...
117	469	Keshav Nagar ...	106.2016348773...	86.28882833787...	106.4427480916...	86.48473282442...	105.5384615384...	85.75000000000...	105.6603773584...	85.84905660377...	Samaypur Badli...	5559.401365265...
118	470	Okhla Village (T...	606.8664850136...	606.8664850136...	608.2442748091...	608.2442748091...	603.0769230769...	603.0769230769...	603.7735849056...	603.7735849056...	Okhla Vihar Sta...	134.0158796835...
119	467	Kirari Gaon	139.3896457765...	139.3896457765...	139.7061068702...	139.7061068702...	138.5192307692...	138.5192307692...	138.6792452830...	138.6792452830...	Nangloi Station	1308.618957670...
120	468	Shahdara Border	151.7166212534...	151.7166212534...	152.0610687022...	152.0610687022...	150.7692307692...	150.7692307692...	150.9433962264...	150.9433962264...	Dilshad Garden ...	231.3171474538...
121	482	R K Puram Sec-7	818.3215258855...	818.3215258855...	820.1793893129...	820.1793893129...	813.2115384615...	813.2115384615...	814.1509433962...	814.1509433962...	Sir Vishweshwa...	939.2174706415...

Table6.2 Distance to nearest hub attribute table

In this paper select the DTC stops/line from each zone which has highest centrality index and compare these data from each zone and also compare the distance to nearest hub (Transfer center) from these selected bus stops and finally we find the connectivity of each zone of Delhi on the basis of centrality indexes and nearest distances from hub.

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The zone wise centrality indexes and distance to nearest hub are shown below-

CENTRAL ZONE

DTC STOPS	Degree centrality	Closeness centrality	Betweeness centrality	Eigen vector centrality	Nearest hub	Hub distance(meter)
Old Delhi	0.001202	16723	45584	0.000121	Chandni chawk	164.83
Red fort	0.00961	16374	77580	0.000112	Lal quila	293
ISBT maharana pratap bus terminal	0.00481	16416	55233	0.0001	Kashmeri gate	165.97
Civil line	0.001602	16313	78580	0.000131	Civil line statn	29.65
Vidhan sabha	0.00961	16322	48480	0.000112	Vidhan sabha statn	24.64

Table 4.1 Delhi central zone centrality and hub distane

NEW DELHI ZONE

DTC STOPS	Degree centrality	Closeness centrality	Betweeness centrality	Eigen vector centrality	Nearest hub	Hub distance(m)
Shivaj stadium	0.001442	15456	17130	0.00012	Rajiv chauk	294.82
Palika kendra	0.001202	15642	16888	0.00011	Janpath station	473.60
Shivaj terminal	0.001402	15431	7668	0.0001	Rajiv chauk	294.82
Gurudwara road	0.000721	15262	47360	0.00002	Central secreteriate	687.82
krishibhawan	0.001442	15630	58172	0.000121	Central secreteriate	108.52

Table4.2 New Delhi zone centrality and hub distance

EAST ZONE

DTC STOPS	Degree centrality	Closeness centrality	Betweeness centrality	Eigen vector centrality	Nearest hub	Hub distance(m)
Mayor vihar phase II	0.00481	21491.99	14654	0.0001	East vinod nagar	48.576
Laxmi nagar	0.00981	18785	137938	0.000112	Laxmi nagar	37.25
Nirman vihar	0.000721	19798	73184	0.000002	Nirman vihar	71.88
Isbt anand vihar	0.001202	22876	22534	0.000112	Anand vihar	178.81
Dilshad garden	0.00981	23282	22884	0.000021	Jhilmil statn	570

Table4.3 East zone centrality and hub distance

SOUTH ZONE

DTC STOPS	Degree centrality	Closeness centrality	Betweeness centrality	Eigen vector centrality	Nearest hub	Hub distance
Mehrauli terminal	0.000241	22467	7756	0.0000112	Qutub minar	1034.56
Lado sarai	0.00721	22086	23417	0.000112	saket	447.66
saket	0.00961	23262	13790	0.000121	Saket	121.12
chattarpur	0.000481	23369	32353	0.00002	chattarpur	482.55
Tb hospital	0.000721	22086	23417	0.00002	GTB Nagar	106.95

Table 4.4 South zone centrality and hub distance

WEST ZONE

DTC STOPS	Degree centrality	Closeness centrality	Betweeness centrality	Eigen vector centrality	Nearest hub	Hub distance
Nawada gaon	0.001202	18942	1055	0.0000121	Nawada statn	91.55
Dwarka more	0.001442	19480	25888	0.000121	Dwarka more statn	69.15
Jharoda crossing	0.000481	22682	561	0.00002	Modern industrial estate statn	2989.68
nazafgarh	0.001682	22756	41630	0.00001	nazafgarh	54.83
Khera more	0.001682	23013	61939	0.000112	Samaypurbadli	3029.45

Table4.5 west zone centrality and hub distance

NORTH EAST

DTC STOPS	Degree centrality	closeness centrality	Betweeness centrality	Eigen vector centrality	Nearest hub	Hub distance(m)
khajuri	0.001202	14504	110292	0.00002	Maujpur station	2663.98
Rajeev nagar	0.000481	19295	1121	0.00001	khyberpass	2821
Gurudwara nanaksar	0.000481	18734	36781	0.00001	khyberpass	2048
Saheedbhagat singh colony	0.00024	22598	576	0	Mundka depot	4604
shastripark	0.000721	18224	18224	0.00002	shastripark	400

Table4.6 North east zone centrality and hub distance

SOUTH WEST

DTC STOPS	Degree centrality	Closeness centrality	Betweeness centrality	Eigen vector centrality	Nearest hub	Hub distance
Dwarka	0.000721	20340.48	175787	0.00001	Dwarka sector 21	311.86
Jhuljhuli xing	0.000481	36218.18	171	0	najafgarh	11878.12
Ghuman hera	0.00481	32903.42	196	0	najafgarh	10935.876
Dhansa village	0.000481	35935.10	8504	0.000112	najafgarh	13100.45
Mundela	0.001202	30691.21	8501	0.00001	najafgarh	9179.84

Table4.7 south zone centrality and hub distance

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Volume 9 Issue VII July 2021- Available at www.ijraset.com

SOUTH EAST

DTC STOPS	Degree centrality	Closeness centrality	Betweeness centrality	Eigen vector centrality	Nearest hub	Hub distance
badarpur	0.00024	27994	0	0	badarpur	101.85
MB road	0.000721	25774.58	29297	0.00002	Taghlakabad	2275.17
govindpuri	0.001682	22685.75	10856	0.000121	Govindpuri	762.50
Tara appartment	0.000721	23391.18	17561	0.00001	Govindpuri	2454.60
CRPF camp	0.000481	23511.73	5730	0.00002	Janakpuri east statn	1438.26

Table4.8 south east zone centrality and hub distance

North west

DTC STOPS	Degree centrality	Closeness centraliity	Betweeness centrality	Eigen vector centrality	Nearest hub	Hub distance
SDM court	0.000721	24331.27	70720	0	Ghevra station	6262.45
mubarakpur	0.001202	21919.82	29663	0.00002	Mundka statn	3299.45
ranikhera	0.00961	22374.75	34397	0.00001	Mundka depot	2200
Karala crossing	0.001682	22502.74	1117	0.00002	Mundka depot	5368.43
ladpur	0.00072	24991.93	75845	0.00001	Ghevra statn	5988.53

Table4.9 north west zone centrality and hub distance

NORTH ZONE

DTC STOPS	Degree centrality	Closeness centrality	Betweeness centrality	Eigen vector centrality	Nearest hub	Hub distance
Bawana	0.001202	26623.79	88378	0.00002	Rithala statn	7631.28
Narela ITI depot	0.000481	27170.04	12510	0	Samaypur badli	11214.11
Narela terminal	0.00961	29868	60980	0.00001	Samaypur badli	12838.56
Bakhtawarpur	0.00721	28095.11	48562	0	Samaypur badli	13825.76
holambi	0.000481	26577	48422	0.0000121	Samaypur badli	10178.63

Table4.10 north zone centrality and hub distance

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The above table shown the centrality index and nearest distance to hub station for each zone of Delhi. we analysis the each zone on the basis of centrality and nearest distance from hub and conclude the connectivity of each zone and defined which zone of Delhi is most connected and least connected and to decide the transit agencies to priorities the funding which is least connectivity.

The analysis of results are done on the basis of centrality and hub distance which are discussed below-

- Degree centrality defined the hub center in the network which is directly connected to the more number of nodes, if node has more degree centrality means more number of node connected.
- Closeness centrality defined the closeness of node in the hub center of network
- Betweeness centrality defined the number of shortest path passes from that node between two node of the network. The node which has higher betweeness centrality means more number of shortest path passes from that node.
- Eigen vector centrality defined the nearest neighbor node connectivity means their neighbor node are more connected means traffic flow from that node is good
- Distance to nearest hub defined the nearest possibility of transfer center to the DTC bus stops if it is less means transfer point is easily accessible from that DTC stops means traffic flow from that node is good.

The zone which has high group centrality and less nearest distance from hub is higher connectivity and easily accessible.

VII. CONCLUSSION

The objective of this research is to develop the centrality index to define the connectivity of multimodal transit network of Delhi. The centrality index is defined for the node connectivity in the network i.e DTC bus and transfer point which is Delhi metro.

The important conclusions drawn from the study can be summarized as follows

A. The centrality index is a parameter which define the node connectivity of network.
B. Distance to nearest hub is a processing tool which determined the connectivity between origin and destination pair of network.
C. Network centrality index for New Delhi and central zone of Delhi are high and the distance from the transfer center (Delhi metro) of each bus stop is very less it means the flow of traffic is good between these zone of Delhi from bus stop to transfer center.
D. Network centrality index for north and North West zone of Delhi is low and the distance from transfer center is high so the traffic flow is poor between transfer centers.

On the basis of zonal centrality we determine the zonal connectivity and hence we priorities our funding according to it. The future extended research is the advancement of connectivity index which also consider the quality of node and link and several factor while calculating index such as speed, frequency, traffic volume and many important route parameter while calculating index which result more advancement parameter for investigation of multimodal transportation network.
The major contributions of the paper include (1) extending the graph theoretic approach to determine the performance of the multimodal transit network; (2) quantifying the measures of connectivity at the node, line, transfer center, and zonal level; (3) applying the methodology to demonstrate the proposed approach in a simplified example problem; (4) examining the transit network performance of NCT Delhi region; (5) providing a comprehensive framework for analyzing connectivity, and efficiency of transit networks for agencies that do not have access to well-developed travel demand and transit assignment models, and (6) integrating the complete methodology in a GIS user interface to enhance visualization, and interpretation of the results. Further this study can be extended to analyze changes in the performance measure with changes to the transit network as a sensitivity analysis; incorporating other attributes to the current formulation, and extending the proposed research for prioritizing locations in the case of transit emergency evacuation.

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