Availability and Accessibility Assessment of Public Transit System in Jaipur City

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Abstract:
Majority of the million plus cities in India are facing serious problems of traffic congestion and pollution due to the unprecedented and rapid pace of urbanization in last decade. City planners are providing solution to these twin problems by developing Mass Rapid Transit System including Metro and BRT in many Indian Metropolitan cities. The availability of transit network and pedestrian accessibility is key issue in planning of effective Public Transit, which affects the ridership significantly. The studies around the globe have shown that lack of accessibility and poor quality pedestrian infrastructure has led to the continued loss of mode share for public transit trips in cities. In the present study, public transit network availability and pedestrian accessibility has been estimated for the city bus routes in Jaipur city. To assess the availability of public transit network on spatial basis, some numerical index has been introduced using GIS tools, based on capacity, frequency and coverage as Public Transit Coverage Index (PTCI), similarly to measure the pedestrian accessibility numerical indices, as Ideal and Actual Stop Accessibility Index (ISAI and ASAI) and Stop Coverage Ratio Index (SCRI) has also been determined on GIS platform. These indices indicate the well served or underserved area by existing transit network and accessibility of a bus stop through the surrounding road network which may help town planners to develop future transit network and also the pedestrian facilities around a bus stop in order to make transit system more accessible and to increase the public transit mode share in the city.

Keywords: Public transit availability, bus stop coverage, pedestrian accessibility, GIS

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1. Introduction

Evaluation methods for transportation system can affect the perceived value of public transit. Different evaluation methods give very different conclusions concerning the value of a particular service or improvement. The selection of evaluation method is not simply a matter of opinion or preference. Comprehensive evaluation is essential for producing accurate results [Litman, 2011]. Evaluating transit service quality from various perspectives, includes factors such as Availability, Frequency, Travel speed, Reliability, Integration, Price structure and payment options, User comfort and security, Accessibility, Universal design, Affordability, Information, Aesthetics and Amenity. Kittelson & Asso. utilized Transit Level of Service Indicator to evaluate the transit system based on Coverage, frequency, span, population and jobs in the city [Kittleson and Asso., 203 a,b].

Transportation demand management includes evaluation of existing transit system and identification of new routes. The transit availability with fair accessibility and supporting conditions of the walking to and from public transit stops determines the usability of the public transit system to draw a sufficient customer base. The investment towards public transit development and the changes in street infrastructure can provide an impetus for area-wide improvements in public transit accessibility.

Public transit systems should not be designed and implemented in isolation [NUTP, 2005]. As system designed in isolation will not be able to shift the choice commuters to public transit. Similarly, by optimizing a transit system's interface with other modal options, system designers are helping to maximize the potential customer base to make the system economically viable. A public transport system does not end at the entry or exit door of the station, but rather encompasses the entire potential user's catchments area [Jumsan et.al, 2005]. If commuters cannot reach a station comfortably and safely, then they will cease to be customers. Access by foot to public transport is the key mode in the developing countries like India, where most of the cities having significant mode share as walk.

Majority of the million plus cities in India are facing serious problems of traffic congestion and pollution due to the unprecedented and rapid pace of urbanization in the last decade. City planners have provided solutions to these twin problems by developing Mass Rapid Transit System including Metro and BRT in many Indian Metropolitan cities [MoUD, 2008].The availability of transit facility with in fair degree of reach and pedestrian accessibility is key issue in planning of effective Public Transit, which affects the ridership significantly. The studies around the globe have shown that lack of public transit network, accessibility and poor quality pedestrian infrastructure has led to the continued loss of mode share for public transit trips in cities [Tiwari, 2001].

The objective of the present study is to develop GIS based public transit coverage indices to evaluate the existing public transit network and pedestrian facilities, which will also be helpful in planning of mass rapid transit system in prioritizing the need of the underserved areas. For which public transit availability and pedestrian accessibility is estimated based on the actual bus capacity, frequency, coverage and pedestrian road network around the stop. For the study area of Jaipur, Public Transit Coverage Index (PTCI), Ideal and Actual Stop Accessibility Indices (ISAI and ASAI) with Stop Coverage Ratio Index (SCRI) were determined on GIS platform to evaluate the public transit system.

2. Literature Review

The Transit Capacity and Quality of Service Manual [TCQSM; Kittelson & Associates 2003] is an excellent supplement to the widely accepted Highway Capacity Manual [HCM; Transportation Research Board 2000], with a systematic framework for addressing various conceptual and methodological issues related to transit capacity analysis and quality-of-service evaluation. As mentioned in the TCQSM, quantifying the quality of service of a transit system is much more complicated than evaluating a highway facility because of the involvement of multiple players (e.g., transit operators, passengers, vehicles) and a wide range of interrelated factors (e.g., spatial and temporal coverage, comfort level, reliability). As a result, the current TCQSM has opted to use multiple LOS measures, instead of one or two measures as the HCM, to evaluate the quality of service of a transit system or its specific components. One of the major disadvantages of using multiple LOS measures is its difficulty to provide an overall quality-of-service evaluation required for comparing different transit routes, travel corridors, or transit systems. The main objective of this study is to explore the possibility of combining some of the LOS measures into a single quality-of-service measure.

Several past studies have made considerable progress on developing service indices to measure transit quality of service. Rood (1997) proposed a service availability measure called Local Index of Transit Availability (LITA), which includes three components: frequency, capacity, and route coverage [Rood, 1997]. Hillman (1997) developed the Public Transportation Accessibility Level (PTAL) index to measure the access availability to the public transit network [Hillman and Pool,1997]. Florida DOT introduced a new quality-of-service measure called Transit Level of Service indicator (TLOS), which is defined as the percentage of time that an average person can use the transit service [Kittelson & Associates and URS, Inc. 2001].

3. Study Area Profile

Jaipur is also known as pink city is an important tourism destination of north-west India and is also the state capital of Rajasthan. Located in the Aravali hills at an altitude of about 430m above M.S.L., Jaipur lies on latitude 26˚55' north and 75˚50' east. The climate is dry with an annual rainfall of 620mm. The city follows a grid plan, with rectangular blocks created by broad intersecting avenues and streets. In terms of population Jaipur is the 11th largest city in India with about 2.3 million people residing in the city (Census, 2001). With its strategic location it has acquired a unique importance as a new centre of retail, commerce, administration, education, production and marketing. In the recent past, this historic city has emerged as the fastest developing city of Rajasthan (Figure 1).

The present public transport system available for the Jaipur is under modification with implementation of mass transit projects such as bus rapid transit system and Metro. The fleet of about 210 buses is being operated under public transport system which connects the city and suburban areas to core area of the city. The private mini bus operators operate about 2900 buses mostly in city area. The private mini bus operators dominate and compete with public bus system. Their routes are in-efficiently rationalized and are not properly regulated with too many buses on some routes where as other routes have very less frequency. The present bus transport system along with improper pedestrian accessibility for public transit system is insufficient to cater the need of city.

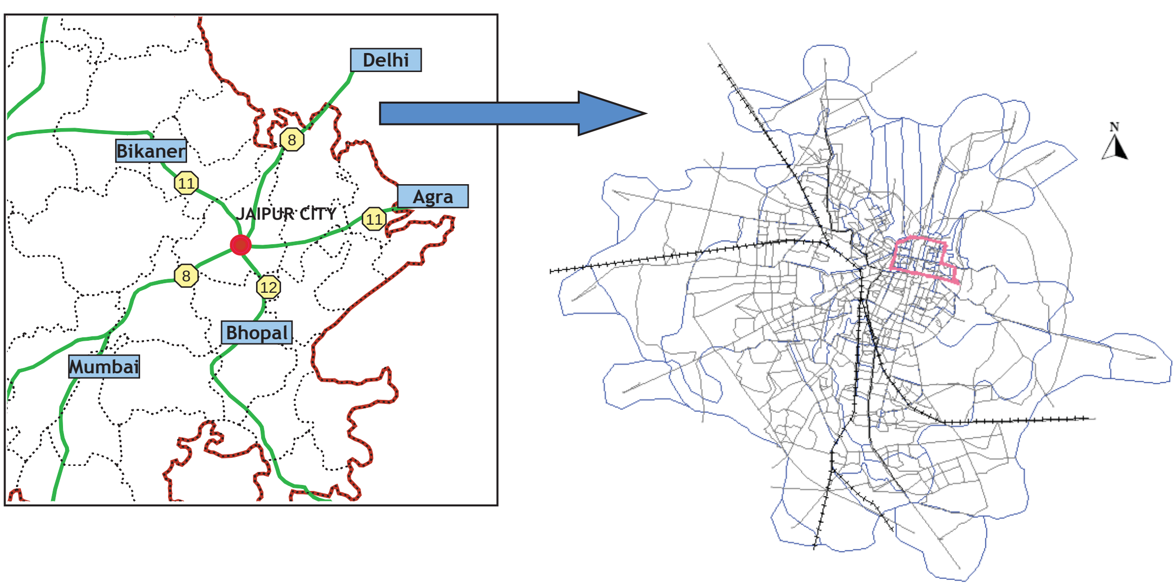

Figure 1. Jaipur City

4. Public Transit Coverage and Bus Stop Coverage

The public transit coverage is the key issue in public transit planning for making the system more user friendly and accessible to maximum people. To identify the new service areas it is necessary to evaluate existing public transit system. The Local Government Commission of the United States, as an experimental measure, first introduced the Local Index of Transit Availability or LITA (Rood 1998) to evaluate the transit system. The public transit coverage for the study area has been evaluated by developing Public Transit Coverage Index (PTCI). The public transit coverage index has been developed [Gebeyehu et. al., 2008] , based on actual seating capacity, frequency and stops coverage has been used and explained in detail in next section.

4.1 Public Transit Coverage Index (PTCI)

PTCI is based on public transit service intensity, which uses capacity, frequency, and route coverage of transit service to scale each Traffic Analysis Zone (TAZ) in the area under study. The capacity measures the total number of seats-km available per capita; the frequency accounts for the number of buses per day and whereas the route coverage is evaluated by transit stops per square kilometer in the area under consideration. Thus PTCI can be expressed as:

PTCI= *f* (capacity, frequency, route coverage)

Bus capacity index (BCI), is the total amount of daily bus seats available to commuters in TAZ, is calculated as a product of the total number of buses arriving at a specific stop in the TAZ, and the number of seats on the bus, and divided by total TAZ population. Bus capacity index for any TAZ is defined in equation (1). Higher value indicates the good availability of person capacity in the TAZ.

$$BCI = (SC \times BN \times L)/P \quad (1)$$

Where, SC is Seating Capacity of the bus, BN is the total number of buses in TAZ, L is route length in TAZ and P is the total population.

Bus frequency index (BFI) as in equation (2) is the total number of buses available in TAZ. BFI is the measure of the service frequency in TAZ. BFI is estimated based on the total daily number of buses on all the routes that have at least one stop in the TAZ. Higher values of BFI indicate the TAZ is sufficient service frequency.

$$BFI = BN \quad (2)$$

Where, BN is total number of buses in the TAZ with at least one stop.

Bus Route Coverage index (BCI) as in equation (3) is the measure of spatial distribution of transit stops in the TAZ .It is estimated based on the total number of bus stops available in the TAZ. BCI is defined as follows. For any TAZ which is having fair bus route coverage should have higher value of BCI.

$$BCI = TS / A \quad (3)$$

Where, TS is the total number of stops and A is the area of TAZ.

The three indies calculated as described above are then added up for each TAZ to estimate the overall Public Transit Coverage Index, while the mean and standard deviation are also calculated, for standardizing the score with the help formula explained below to evaluate the public transit network on the common scale.

Standardized score = ([capacity, frequency or coverage score] - [mean of distribution]) / [Standard deviation]

After normalizing the index, the degree of coverage of transit service available is correlated to that area's population and land use as shown in Figures 5, 6, 7 & 8. The overall PTCI score of each analysis zone then calculated by summing up all the three indices as per equation (4) and the result are joined with the GIS map to analyze the each TAZ graphically, which areas are well served or underserved by the existing bus supply.

Overall PTCI score = ([capacity score] + [frequency score] + [bus coverage score]) (4)

4.2 Bus Stop Coverage

Determining transit stop coverage is another important issue in Pubic Transit Planning .The presence or absence of transit stop near one's origin and destination is key factor in one's choice to use transit. When stop is not available, other aspects of public transit service do not matter for given trip. Transit stop service will be provided within a reasonable walking distance of one's origin and destination which will enhance one's choice to use transit services in the nearby vicinity. Bus stop coverage area is the area covered by a particular route within working distance of transit stop. This area is defined as the air distance within 400m of a bus stop or 800m of rail station in TCQSM (Transit Capacity and Quality of Service Manual, TCRP Report 1999), Figure 2.

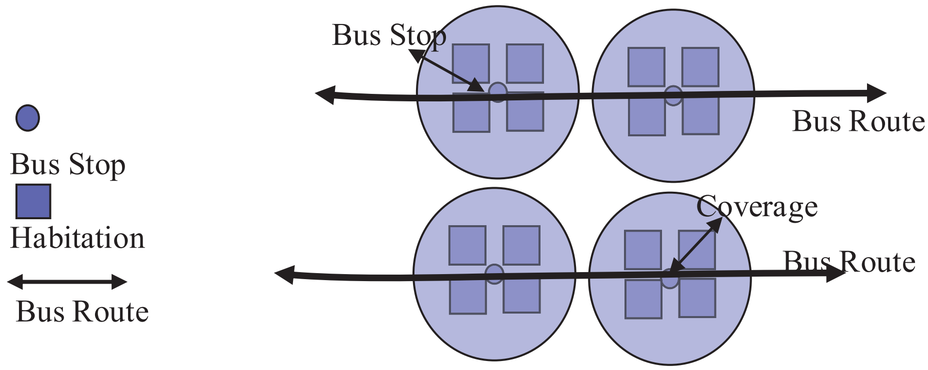

Figure 2. Concept of Coverage Area

4.2.1 Ideal, Actual Stop Accessibility Indices (ISAI and ASAI) and Stop Coverage Ratio Index (SCRI)

To evaluate the accessibility of existing bus stops in the study area, out of the different city bus routes available in Jaipur one route with maximum ridership was selected for estimating Ideal and Actual Stop Accessibility Indices (ISAI and ASAI) and Stop Coverage Ratio Index (SCRI) on GIS platform based on the concept given by Foda and Osman[Foda and Osman, 2010]. These indices can be used to evaluate both the accessibility to a bus stop through the surrounding pedestrian road network and the ratio of actual access coverage to the ideal access coverage of a bus stop. The idea here is to identify all the pedestrian road network links that lie within the specified maximum walking distance of the 400m access threshold, measured along the network paths around the bus stop. Joining the ends of those links creates a polygonal area, which is referred to as the "actual access coverage" for the bus stop. This polygonal area is considered more representative than a 400m circular buffer for measuring the access coverage of a bus stop. Figure 3 shows the difference between the ideal access coverage (circular area) and the actual access coverage (polygonal area), which causes an overestimation in assessing the access coverage of a bus stop at a given location.

The Ideal Stop-Accessibility Index (ISAI) as in equation no. 5, can be used to evaluate the accessibility to a bus stop through the surrounding pedestrian road network. The resulting value of ISAI represents the ideal pedestrian road network density within the access threshold from a bus stop (Km/Km2). As previously stated, the ISAI value represents the accessibility to a bus stop through the surrounding pedestrian road network. An increment in the index value means that the ideal pedestrian road network density is higher, which is interpreted in terms of a better connectivity between the bus stop and the surrounding pedestrian road network; hence, the bus stop is more likely to be accessible, and vice versa. In other words, the higher the value of the ISAI, the more accessible the bus stop location.

$$ISAI = L_P / A_C \quad (5)$$

Where, L_P is total length of the pedestrian road network links lying within Circular buffer of 400m (Km) and A_C is area of ideal circular buffer (Sq. Km) as shown in Figure 3.

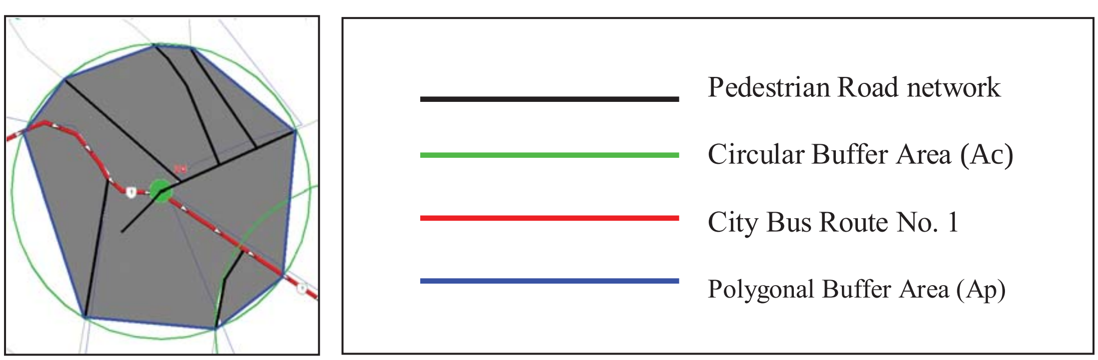

Figure 3. Ideal (Circular) and Actual (Polygonal) Bus Stop Access Coverage

Actual Stop-Accessibility Index (ASAI) as in equation no. 6 can be used as a more accurate measure of bus stop accessibility through the surrounding pedestrian road network. It is believed that the ASAI provides a more realistic measurement than the ISAI to the pedestrian road network density around a bus stop. The resulting value of this index represents the actual pedestrian road network density within the access threshold from a bus stop (Km/Km2).

$$ASAI = L_P / A_P \qquad (6)$$

Where L_P is total length of the pedestrian road network links lying within a walking distance of 400m measured along the network paths (Km) and A_P is area of actual polygonal buffer (Sq. Km) as shown in Figure 3.

The Stop Coverage Ratio Index (SCRI) as in equation no. 7 is used to evaluate the ratio of actual access coverage to that of the ideal access coverage of a bus stop. This can be calculated with the equation given below. The resulting value of the SCRI is dimensionless, in which it represents the ratio of the actual access coverage to the ideal access coverage of a bus stop. Such an index is an indicator of the degree in which the location of the bus stop actually covers the surrounding area in other words, the percentage of actual access coverage with respect to the ideal access coverage. Theoretically, the SCRI value varies from a minimum of 0.0 if the bus stop is not served with a pedestrian road network to a maximum value of 1.0.

$$SCRI = A_P / A_C \qquad (7)$$

Where A_P is area of actual polygonal buffer (Sq. Km) and A_C is area of actual circular buffer (Sq. Km) as shown in Figure 3.

5. Application of the Concept

For the application of the concept discussed above, the city of Jaipur, one of the growing metropolitan cities in India has been selected. The study area has been divided into seventy traffic analysis zone (TAZ) as per the census data available from the census department and Jaipur development authority. The existing road network and bus routes information has been digitized with the help of various user friendly tools in TransCAD state-of-the art GIS based software as shown in Figure 4 to estimate the different index parameters.

On evaluating the data from the above Figures the BCI, for all the TAZs it is evident that area around CBD and area on western side of the city including major residential areas as Mansarovar, Jothwara, Vaisahli Nagar etc. have index

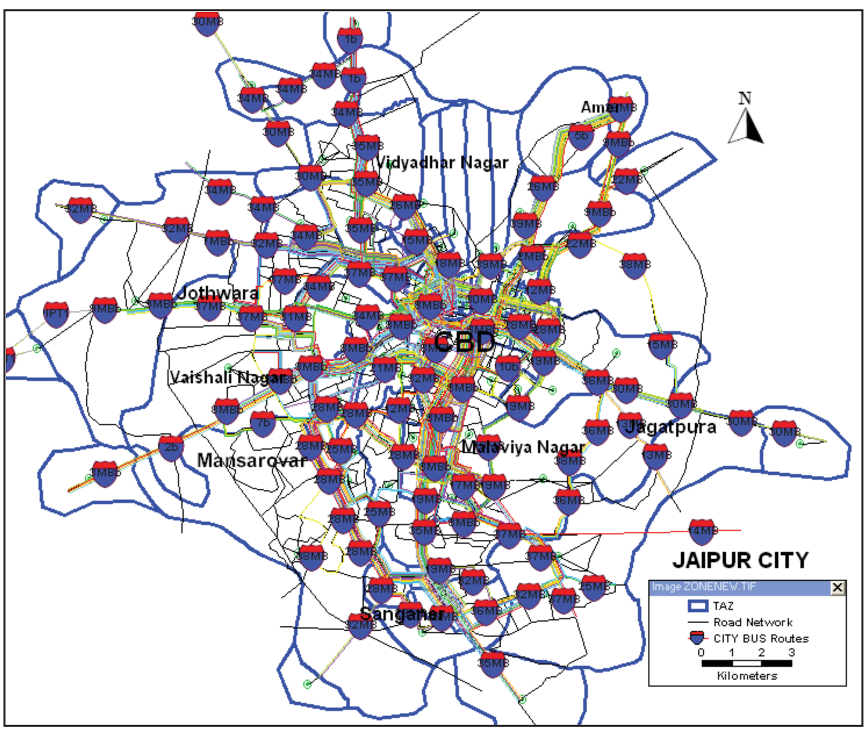

Figure 4. Jaipur City with TAZ and Public Transit Routes

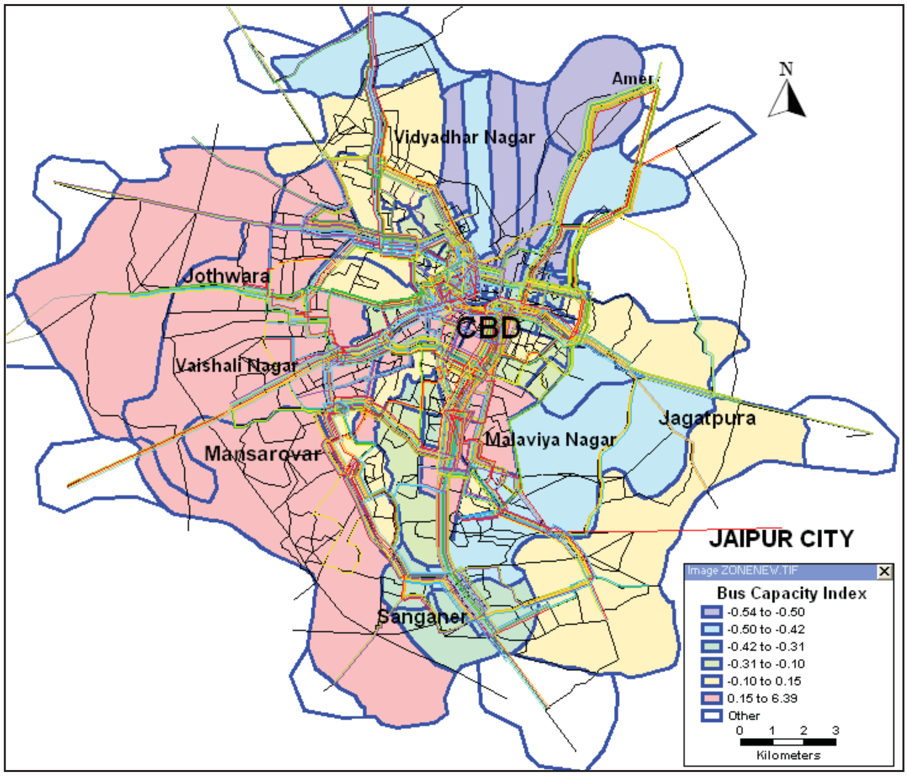

Figure 5. Bus Capacity Index

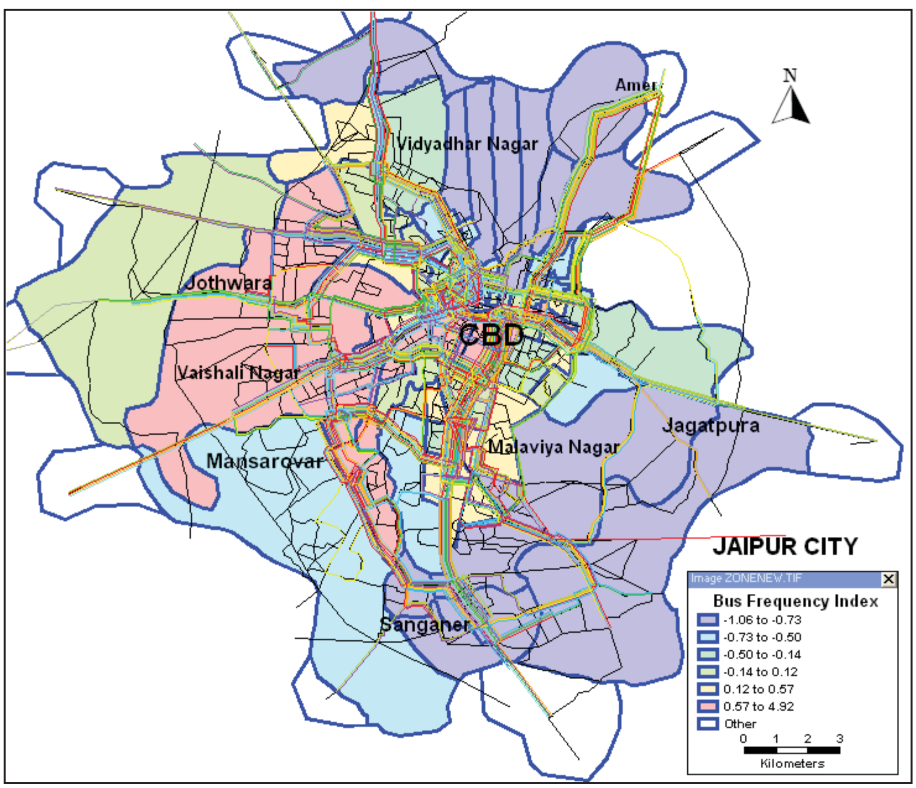

Figure 6. Bus Frequency Index

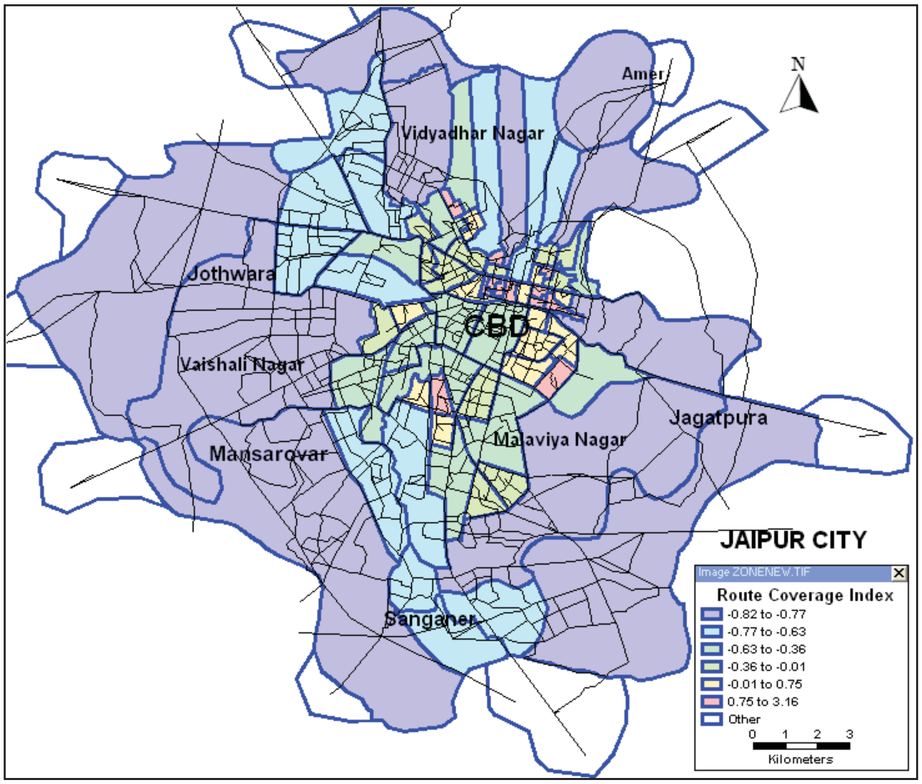

Figure 7. Bus Route Coverage Index

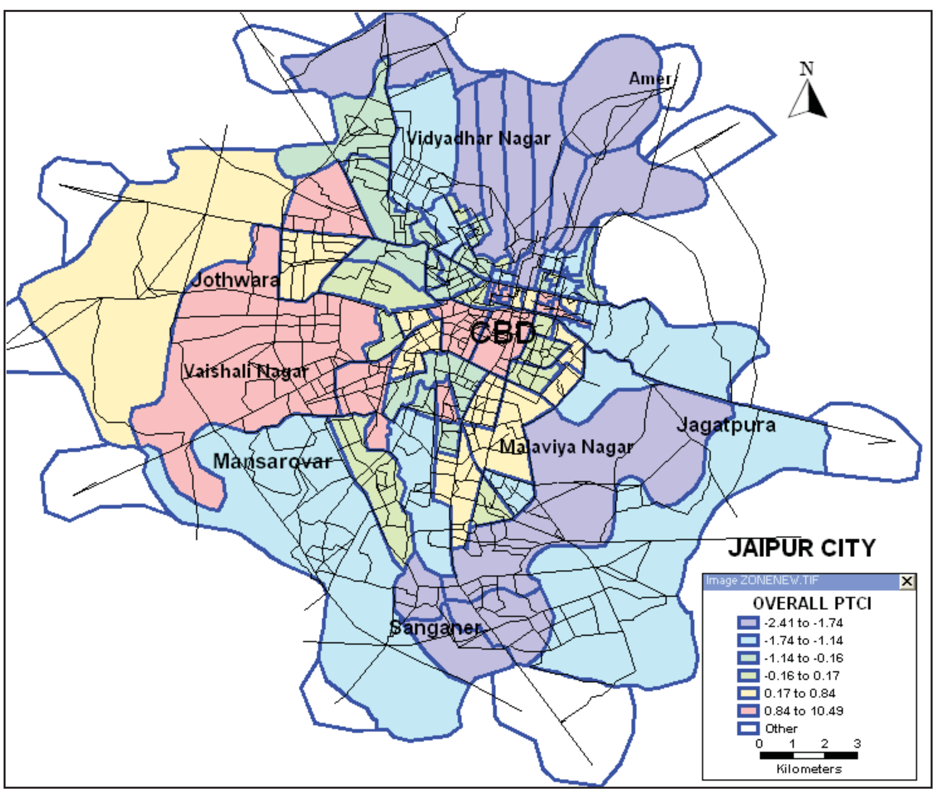

Figure 8. Overall Public Transit Coverage Index

value ranging 0.15- 6.39, which indicates higher person capacity in these TAZs as compare to other TAZs. The higher BFI ranging 0.57-4.92 for Mansarovar, Jothwara, Vaisahli Nagar etc indicates that areas on city periphery have low service frequency as compare to these areas and areas near by CBD. Similarly, the BCI with higher values ranging 0.75- 3.16, has shown that major residential and commercial area along the north-south transit lines have better route coverage than other TAZs.

Similarly, to analyze the stop accessibility of existing City bus routes in the study area one major route No. 1 was identified as a case study (Table 1) for the proposed analysis in this paper, with a length of about 10.26 Km and covering an area of 13.66 km^2 starting from the Sikar bypass in the north to Transport Nagar in east represents one of busiest route from ridership point of view as shown in Figure 9.

The route is densely covered with commercial area and crosses the central business district (CBD). Further, 15 bus stops were identified serving the bus routes from north to east, as shown in Table 1.City Bus Route No.1 from Sikar bypass to Transport Nagar was selected to find out accessibility and coverage of public transit stops. As discussed in above sections the results of ISAI, ASAI and SCRI for the selected route are as presented in Table 2.

Examining the ISAI value from the above table for the selected route it is clear that Arya Square stop has the minimum value of 2.68, Which indicates that the availability of the pedestrian road network is minimum around the stop and has poor accessibility, While the stop Badi Chopad has maximum value of 11.94, which means the stop has good pedestrian road network

Table 1. Bus Stop along City Bus Route No.1

SN.	Stop Name	SN.	Stop Name
1	Sikar bypass (North)	9	Arya Square
2	Sun & Moon	10	Karani Palace
3	Alka	11	Chand Pole Gate
4	Khaitan	12	Chhoti Chopar
5	Bhavani Niketan	13	Badi Chopar
6	Chomu Pulia	14	Ghat Gate
7	Ambawadi	15	Transport Nagar (East)
8	Panipech		

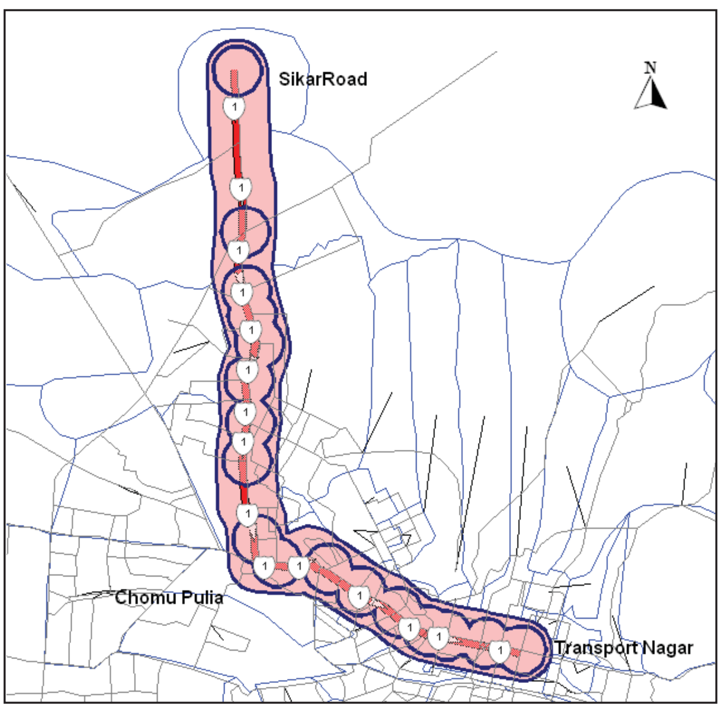

Figure 9. Route No.1 from Sikar bypass to Transport Nagar with Circular buffer zone

Table 2 ISAI, ASAI, and SCRI Values for Bus Stops along City Bus Route No.1

SN.	Stop Name	Ideal circular Access Coverage (Sq. Km)	Actual Polygon Access Coverage Area (Sq. Km)	Pedestrian Path (Km)	ISAI	ASAI	SCRI
1	Sikar bypass (North)	0.503	0.345	3.34	6.64	9.68	0.68
2	Sun & Moon	0.503	0.344	1.57	3.12	4.56	0.68
3	Alka	0.503	0.243	2.54	5.04	10.45	0.48
4	Khaitan	0.503	0.244	1.89	3.75	7.74	0.48
5	Bhavani Niketan	0.503	0.365	2.01	3.99	5.50	0.72
6	ChomuPulia	0.503	0.423	4.57	9.08	10.80	0.84
7	Ambawadi	0.503	0.367	1.57	3.12	4.27	0.72
8	Panipech	0.503	0.415	2.46	4.89	5.92	0.82
9	Arya Square	0.503	0.146	1.35	2.68	9.24	0.29
10	Karani Palace	0.503	0.198	1.78	3.53	8.98	0.39
11	ChandPole Gate	0.503	0.489	4.24	8.42	8.67	0.97
12	Chhoti Chopar	0.503	0.424	5.34	10.61	12.59	0.84
13	Badi Chopar	0.503	0.455	6.01	11.94	13.20	0.90
14	Ghat Gate	0.503	0.323	2.58	5.12	7.98	0.64
15	Transport Nagar (East)	0.503	0.342	5.21	10.35	15.23	0.67

and also have better accessibility as compared to Arya Square. Further, the ISAI value should always not be greater than the ASAI, as the actual access coverage area will not exceed the ideal.

Another accessibility index ASAI, shows that Ambawadi stop has the minimum value of 4.27, which indicates that it has minimum actual pedestrian road density among the rest of the stops, Whereas, the Transport Nagar stop has achieved the maximum value of 15.27, indicating maximum density of pedestrian road network among rest of the stops, which intern indicates suitability of its location from spatial perspective. It should be realized that the actual access coverage area and its shape for calculating ASAI are affected by the geometry of the pedestrian road network around the bus stop within the suitable walking limit. Finally, the SCRI values for different transit stops which indicate Arya Square stop has minimum actual coverage than Chand Pole Gate stop which has the maximum actual stop coverage.

6. Conclusions

Form the above discussion following conclusions can be drawn

- Evaluation methods for transportation system can affect the perceived value of public transit as different evaluation methods give very different conclusions concerning the value of a particular service or improvement which clear from the comparison of ISAI and ASAI.
- Continuous evaluation of transit service quality from various perspectives, such as Availability and Accessibility is necessary for better performance.
- The overall Public Transit Coverage Index indicates that area near CBD and residential areas on western side including Mansarovar, Jothwara, Vaishali Nagar etc. has good overall coverage of bus service.
- The overall Public Transit Coverage Index for any transit service should have high value for high ridership.
- The stop coverage index for any public transit stops should be nearly one to have a sufficient pedestrian road network around the transit stops.
- GIS has proved as a powerful and user friendly tool to evaluate the public transit facilities in a city. Transport planners has graphical out put of the data analysis and its easy to interpret the implications of the any new facility provided to the users.
- The indices analyzed here may help urban transport planners to prioritize the development of future mass transit network and pedestrian road network around the stops to make system more attractive for choice riders.
- If the indices used for evaluation show a low efficien-

cy transit system, the bus frequencies & capacity, route coverage, number of stops and pedestrian network around the bus stop need to be increased as remedial measures.

• The indices are helpful in evaluation of transit system already in use or under planning. Indices are calculated on GIS platform and analyzed as per range suggested in the study. If the index calculated falls with range of acceptance than it is performing well, on the contrary its need to be improved to enhance the index value. The low or high numeric value is an indicator of performance of transit system.

7. Acknowledgment

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