MULTILEVEL FRAMEWORK FOR OPTIMIZING BUS STOP SPACING

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Abstract

To meet the rapidly growing urban mobility needs and control personal vehicles activity and their impacts, it become necessary to timely maintain and enhance the public transport system in Indian cities. In Indian cities public transport mainly defendant on buses, and likely to continue for coming years. However, the public bus transit system is inaccessible, inadequate and unaffordable to passengers. The paper present a multilevel framework for optimization of bus stops based on three different types for enhancing performance of public transport. Bus stops are classified as connection stop (C-stops), key stop (K-Stops) and ordinary stop (O-Stops). Firstly the C-stops have been identified on the basis of transit facilities. After that K-stops and O-stops are traced out using the transit demand and buffer analysis in Geographical Information System. In this work the spatial analysis of study area using GIS plays significant role.

Keywords: *Coverage Model, GIS, Smart City, Key Stop, Ordinary Stop*

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1. INTRODUCTION

In metropolitan cities, public transportation plays important role to comply with the increasing population and complicated land use structures with respect to mobility. Availability of numerous job opportunity centers, education facilities, increase in urban population and family incomes call for efficient urban movability in India. Several middle class families are permissively investing high amount for having private vehicles such as motorized two wheeler and cars for transportation. Meanwhile, there is absence of serious actions to diminish the intense rise in vehicle possession by individuals. This further promotes the use of vehicles for any non-important works. The excessive use of private vehicles raises several issues related to quality of life such as traffic congestion, huge rise in accident rates, and increase in noise pollution and greenhouse gas emissions [1].

India has experienced intense rise in motor vehicle in recent years (see chart-1) this lead to interest of environmentalist, government officials, researchers and student for a number of reasons. Already, India's vehicles have had a tangible harmful impact on the environment [2]. For example, count of registered motorized vehicles grown rapidly from approximately 0.3 million in 1994 to 55 million in 2001, and moved up to an astonishing 141.8 million in 2011 [4], as depicted in chart-1. Some analysts envisaged that India's motorization rate will persist in to grow to 42 vehicles per 1000 by 2020 [2]. The high growth rate of the motor vehicles has been found out in the metropolitan cities. On the other hand, the urbanization of big Indian cities results in more interval of regular trip that entail higher traffic demand as well as more vehicular travelling [3]. Therefore, a number of trafficking issues came into picture consequently.

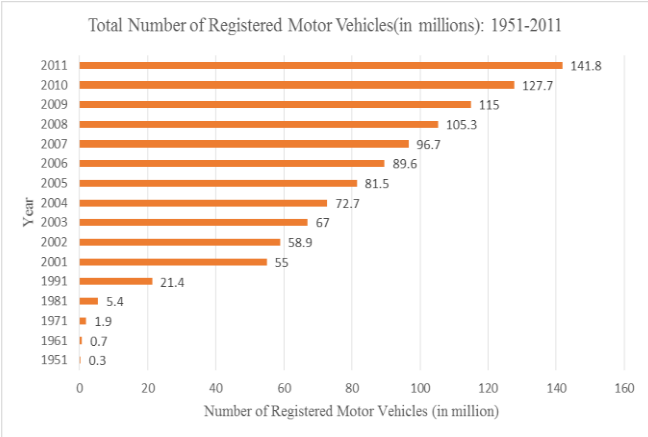

Chart -1: Number of registered motor vehicles in India. [4]

For example, Indian cities are facing many global environmental issues such as, consequence of air pollution and Green House Gas emissions. Due to timely rise in fuel prices and traffic call the costs of travelling increases day by day. In addition, several problems have aroused such as traffic congestion, accidents, increasing vehicle pollution in most of the metropolitan in cities in India [4]. Public bus transport has been recommended for diminishing environmental impact of transport and providing movability in metropolitan cities. Public transport service is a key aspect of the quality of urban life and a determinant of competitiveness and attractiveness of a territory. Major metropolitan cities in the world are endowed multi-level transport service, as for metro rail, bus rapid transit (BRT), and bus transport. Spacing of bus stop is a crucial measure in employing public transport services [5]. In developing cities it becomes necessity to structure an effective public transport system to comply with changing transport requirement. Whereas, while structuring transit service, urban agglomeration has to be considered for connecting it with existing one.

However, irrational spacing and allotment of transit stops results in to a low quality of public bus transport. For example, irrational allotment of transit stops inside the boundaries of central business districts (CBD) leads to unwanted bus stopping and long waiting time [6]. Due to dispersed land use pattern bus stops are not in walking accessibility condition [7] and results in less satisfaction of public transport demand. To enhance the performance of public transit system it is necessary to optimize the distance between bus stops. Typically, in the optimization of allotment and spacing of bus stops various coverage models have been applied with high emphasis on the spatial data. This paper has introduced a multilevel approach for optimization of bus stops spacing in the city of Aurangabad in India, where a smart public transport system is outlined and under development with respect to the smart city.

2. LITERATURE REVIEW

A review of present literature unveils that spacing and allotment of transit bus stop is a most pertinent topic which has evoked the awareness of city planners and researchers. The established standards are most fundamental aspect while spacing the transit bus stops, which usually ranges in 400 to 600 m in urban area. The average walking distance to board or alight a bus from the location of individual is 300 to 400 m [8]. Suitable and easy access to public transit system is typically characterized as a tolerable walk under normal conditions. Stopping of buses at each stop takes time, for a certain bus route with a specified length the bus stops which are closely located results in wastage of time and space. Whereas, those are sparsely located results in higher walking distance for commuters or force to take other modes of transport. Besides that to improve the efficiency of bus transport system there should equivalence between stop spacing and speed of buses. The allotment and spacing of transit stops has been closely related with land use pattern and transit trip demand [9].

To find out most favorable spacing of bus stops in the Birkenhead region of Auckland El-Shair used GIS technology. In this work, it was presumed that, if all the bus stop covers 80% or more of the CBDs or land use then the bus stops in that area were adequate [10]. The use of GIS and GPS was carried out for analyzing bus stops location between the route Vadapalani and Besant Nagar in Chennai, India [11]. In their research, they observed some bus stops were closely spaced, which results in a wastage of crucial time as well as area. Whereas, several bus stops was found to be risky in such a manner that poses a harmful to the nearby vehicles, causes traffic blockage and air pollution. Similar issues were raised in the study of Riyadh city, Saudi Arabia. To find out appropriate bus stops the multi-criteria buffer function was used in Arc-Info GIS on various parameters such as, distance, land use pattern, willingness to walk. The coverage of bus stop plays important role while evaluating performance of entire bus transport system. The stop coverage is the basis for calculating the share of population covered by the public bus transport system. When two stops are too closely spaced then it may cause redundancy. On the basis of various land use pattern the service distance standard changes, such merit indicates the notion of coverage [12], where a given location (home, college, place of employment, school, garden, shopping center etc.) is suitably serviced by a bus stop if it is within the specified access distance.

The coverage location frameworks of three different types had briefly explained by the A.T. Murray, Tong and Kim (2010). In that firstly they find out the entire need with minimum provision with the location set covering problem (LSCP) model. In the second step, they explained maximum covering location model which permits possible coverage need by using minimal facilities and finally they trace out the other possible provision available had considered to increase the availability of service.

This framework provides a way for the optimization of service in particular area, for example school, college, transit provisions [13], by taking into account the ability of finding the coverage, this model is generally followed [6] [14]. Zhengdong Huang (2014) had introduced a hierarchical model which was used in the optimization of bus stop spacing. In this work, bus stops were categorized into multiple level and by using two different coverage model transit need and spatial coverage improved respectively. The result shows the significant amount of increase in land area coverage and transit demand [14].

3. STUDY AREA

Aurangabad is a rapidly growing metropolitan city with 11, 89,376 population & a land use area of around 138.44 sq. km. As a historical city, it crowns various famous tourists places Bibi-Ka-Maqbara, Panchakki and ancient 12 doors. It also acts as capital city of Marathwada region of Maharashtra & located geographically south-west in India as shown in fig-1.

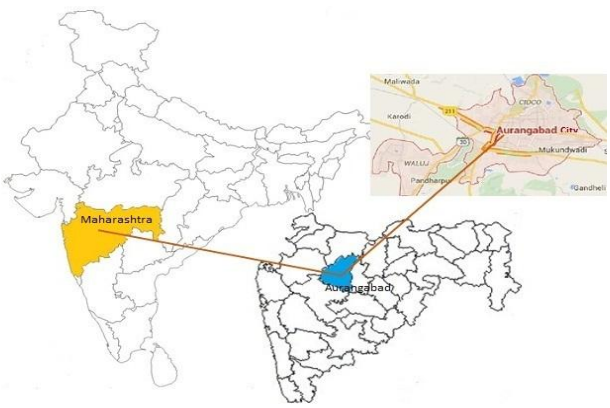

Fig -1 Geographical location of Aurangabad city

The rapid growth in urbanization with intense rise in population and quick economic swelling results in outrageous transport need. Till 2016, five bridges have been built and two bridges are in construction phase. Currently, there are two bridges that satisfy main passage of public bus transport. The public bus transport system in Aurangabad consists of bus, auto-rickshaw, Ola taxi transport. With 65% of share travel demand and around 3 lac commuter trips daily in 2014, bus transport mode plays crucial role. However, to change and take command over auto-rickshaw oriented service, the city municipality has put great prominence on public bus transport system since 2015 to make strong pavement for Smart City initiative [15].

4. METHODOLOGY

The public transit planning usually starts with designing of routes, better planning of fleet in peak hours and in dense area. An alternative concern in the public transit planning is accessibility. This component of operational planning greatly influences the travel time and accessibility of individual. Optimization of bus stop spacing has encountered considerable attention in transit planning [16] [17]. The optimization of bus has been carried out in multilevel steps (see fig-2). The recognition of connection stops (C-stop) with respect to current transport provision as airport, railway and park & ride locations. In the next step, key stops (K-stop) are computed with the help of coverage model for reducing spacing with the consideration of Chowks and T-points. Finally, to maximize the spatial coverage for satisfying the transit demand a coverage model was proposed.

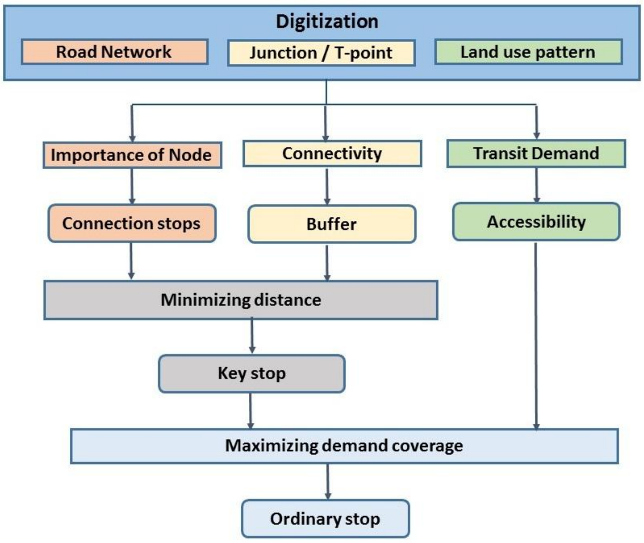

Fig -2 Methodology

The framework basically relay on the geographical information system (GIS) technology. ArcGIS is platform of GIS developed by Environmental System for Research and Innovation (ESRI) used for integrating different types of data. For planning of public transit system, With GIS application, one can compare locations of multiple things in order to discover how they spatially relate to each other. By using the feature of buffer analysis transit demand in the particular bus stop area has been evaluated to maximize the coverage. The vector data model in GIS has been used for representing spatial feature (refer table-1) and the geographical co-ordinates of bus stop, Chowks and T-point are collected using an android application Open Data Kit (ODK) [15].

Table -1: Spatial Features

Sr. No.	Geographic Features	Feature Class
1	Chowk	Point
2	Bus Stop	Point
3	T-Point	Point
4	Road	Line
5	Study area	Polygon
6	Bridge	Point

The optimization of K-Stops and O-stop has been carried out by using two different types of coverage models.

4.1 Find out connection stops

The various modes of transport facilities are the backbone of city and they should be actively connected with each other. In this step connection stops are identified with respect to the different modes of transport facilities as airport, railway station and park & ride station, closest node to these provisions are assigned as connectivity points to each other i.e. connection stops.

4.2 Optimization of key stops

The Chowks, T-points and connection stops are considered in the optimization of key stops. The main goal of this model is to minimize the distance between the bus stops. The centrality of the node in the road network is used to calculate the weight. The mathematical formulation is described as below [14],

$$\text{Min} \sum_{k} \sum_{i} r w_i d_{ik} y_{ik} Y_k \quad \ldots (1)$$

Subject to

$$\sum_k Y_k = p + q$$

$$\sum_k y_{ik} \leq 1, \forall_k$$

$$Y_k = \begin{cases} 1 \text{ chosen} \\ 0 \text{ otherwise} \end{cases}$$

$$y_{ik} = \begin{cases} 1 \text{ if } d_{ik} \leq D \text{ and } \sum_{j \neq k} y_{ik} = 0 \\ 0 \quad \text{otherwise} \end{cases}$$

Where,

i = node in the network

j, k = connection stop,

rw_i = random walk at node i,

td_i = transit demand at node i,

d_{ik} = spacing from node i to stop k,

y_{ik} = if node i covers stop k then equals to 1 otherwise 0,

Y_k = if connection stop k chosen then equals = 1 otherwise 0,

D = Maximum coverage of bus stop,

p = Total count of C-Stop,

q = Total count of K-Stop,

r = Total count of O-Stop.

4.3 Optimization of Ordinary Stops

To generate the ordinary stops the input from previous model are considered in the form of C-stops and K-stops. To achieve objective of this model transit demand at each bus stop is calculated for maximizing the passenger coverage. This model basically requires maximum serving space between stops that transit commuters are ready to travel over is 400 – 450m for boarding bus. After evaluating transit demand for each bus stop the total transit demand of a city comes into picture. The model for maximizing transit demand is defined as follows [14] [18]:

$$\text{Max} \sum_k \sum_i td_i \, y_{ik} Y_k \qquad \text{… (2)}$$

Subject to

$$\sum_k Y_k = p + q + r$$

$$\sum_k y_{ik} \leq 1, \forall_k$$

$$Y_k = \begin{cases} 1 \; chosen \\ 0 \; otherwise \end{cases}$$

$$y_{ik} = \begin{cases} 1 \; if \; d_{ik} \leq D \text{ and } \sum_j y_{ij} = 0 \\ 0 \qquad\qquad otherwise \end{cases}$$

5. OPTIMIZATION

In the process of optimization by considering the available data in the form of road network, public transport route, population data, land use pattern has been collected. There are 280 bus stops in the city including 200 new and 80 old bus stops. The geographical co-ordinates of bus stops are collected using Open Data Kit (ODK) android based application [19]. The co-ordinate data is visualized i.e. mapped on the toposheet of Aurangabad city (collected from Survey of India (SOI)) in ArcGIS software. Fig-3 shows irregularly spaced existing bus stops in the study area.

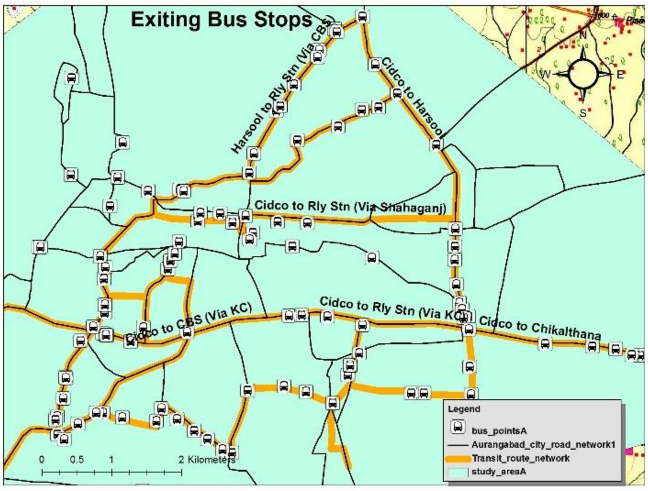

Fig -3 Existing bus stops

The city has good transport connectivity by means of airport, railway station, national and state highways [20]. The network nodes near to transport facilities are identified as connection stops and mapped on the toposheet. There are 8 nodes identified as connection stops. In the second step, the major Chowks, T-point and connection stops are considered as input for optimization. The node centrality value is calculated for each Chowks and T-point with random walking distance 400- 450 m for boarding bus [21] [22]. So, there are 35 bus stops needs to be optimized in this step. Finally, optimization of ordinary stops has been carried out based on the transit demand. The focus is on to maximize the spatial coverage. The buffer of 300 and 400 m are created to track out the coverage of bus stops including connection, key and ordinary stops. In this work, 130 O-stops has been optimized and around 173 stops came into picture including C-stop and K-stops.

6. RESULT AND DISCUSSION

The use of GIS for spatial analysis of study area provides satisfactory results in terms of buffer creation of bus stops. Optimization of bus stops also greatly influenced by the spacing between them. By setting different limits for buffer it becomes easier to compute land area coverage and population coverage of particular bus stop. The land use pattern as job locations, habitat of individual has been serviced by bus stops, therefore to achieve better results with population, job coverage should be included. The many of the existing stops are having distances below 200 or above 800 m. So, after optimization most of the bus stops have distances between 350 to 400 m. Fig. 4 shows different types of bus stops and transit facilities available in the study area with optimization.

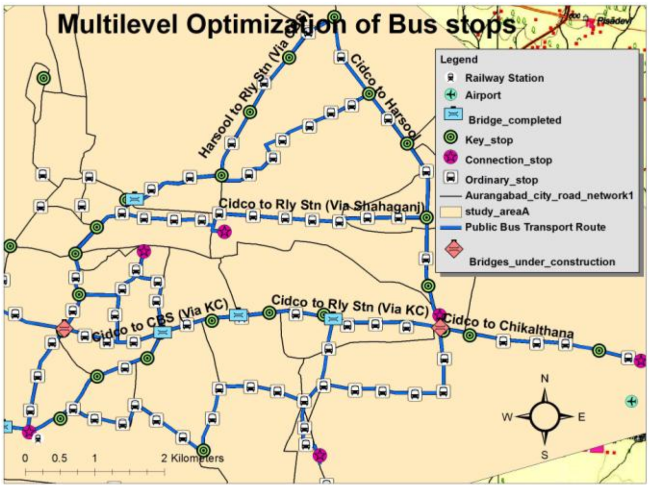

Fig -4 Multi-level optimization of bus stop

The buffer of limit 400 m (ref. Fig-7) has better coverage value than buffer of 300 m (ref. Fig-5) with respect to land area. After optimization, the coverage of population and land area has been considerably improved; the growth in the coverage of land use area is addressable.

Table 2 Feature class optimization

Sr. No.	Feature	Existing	Optimized
1	Chowks	39	23 as K-stop
2	T-point	9	6 as K-stop
3	Bus stops	180	120 as O-stop
4	Transit point	12	6 as C-stop

In table-2, it shows statistic of various feature classes in existing and optimized format. In the study area 39 Chowks has been found out, whereas 23 Chowks optimized as Key stop. The Chowks, T-points and bus stops on the bus transport route has been considered for the process of optimization.

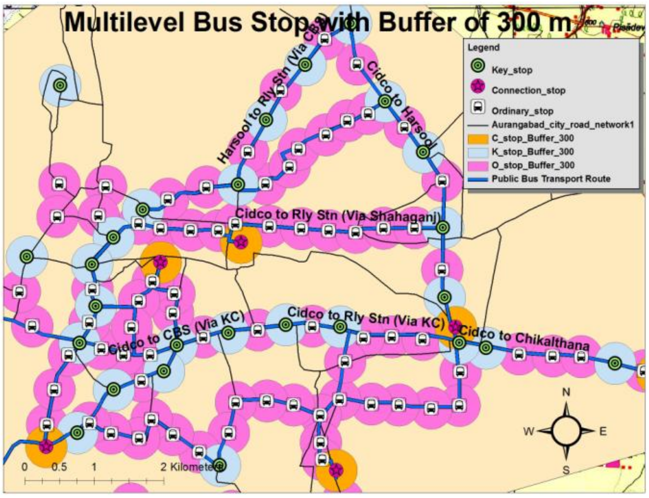

Fig -5 Multi-level bus stop with buffer of 300 m

Table-2 Spatial areac overage

Public transport system	Spatial area coverage (km2)	
	300 m buffer	400 m buffer
Existing	46.16	72.55
Optimized	61.23	91.71

The table-2 shows different buffer coverage values in km^2. In existing system with 300 m area coverage is 46.16 km^2, and with 400 m it covers 72.55 km^2. Whereas, in optimized system it shows significant improvement with 61.23 km^2 with 300 m and 91.71 km^2 400 m buffer.

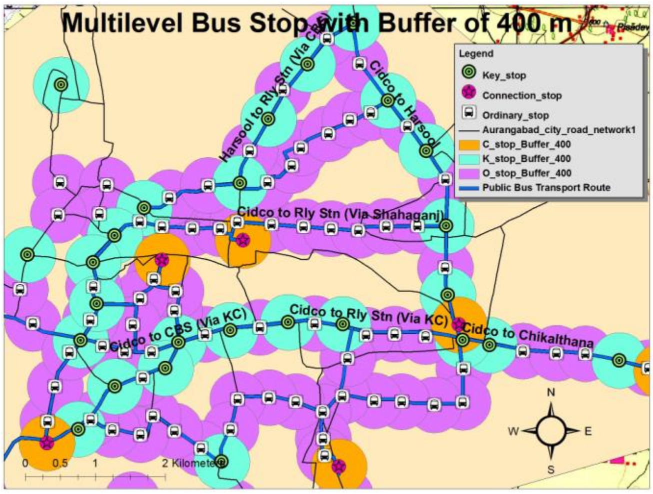

Fig -6 Multi-level bus stop with buffer of 400 m

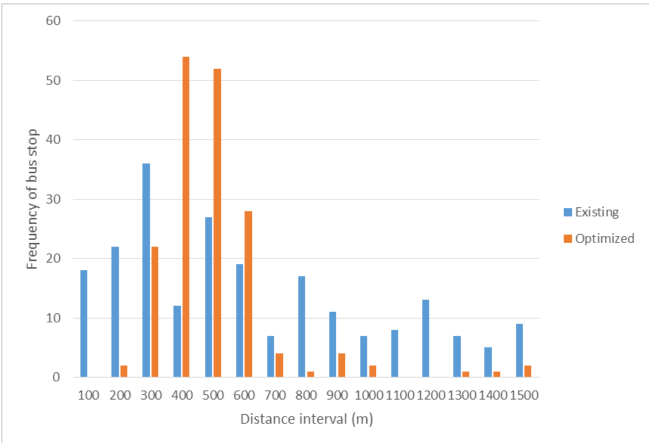

Fig -7 Distribution of distance between stops

The spacing between bus stops in the existing and optimized is depicted in Fig -7. In the existing system bus stops are spaced irregularly, whereas optimized system shows most of the bus stops are in the range of 400 to 600m. By using the function in GIS it becomes easier to find out the distances between adjacent stops along the road network. The spacing of bus stops is classified by an interval of 350 m to 400 m in the road network. In the process of optimization, Chowks and T-points which are outside of the city or in agglomeration not considered. Transit provisions and normal stops outside of the city or in agglomeration also not included. To maximize the passenger coverage, transit demand at each bus stop has been calculated. For this purpose ward-wise population dataset from Municipal Corporation has been considered. The population is sparsely distributed among the different wards as well as in the urban agglomeration called Waluj MIDC, Pandharpur, and Nakashtrawadi. The population coverage has been significantly improved by using coverage model. For example on route no. 09 with reduction in count of bus stop from 21 to 18, it shows better coverage with optimized system (refer table-4).

Table -4 Statistic of population coverage

Route no 09	Population coverage	
	400 m buffer	500 m buffer
Existing	1,95,573	1,98,524
optimized	1,03,928	1,21,621

The population coverage may vary according to the land use pattern as school, colleges and job locations, which limits this model. The commuters arriving from nearby villages at railway station and central bus stand are also not included in the study. To get better coverage land use pattern such as, govt. offices, hospitals, school, colleges and job locations should be included with spatial data.

7. CONCLUSIONS

Access and accessibility are two crucial components to have sustainable public transport system. To serve the increasing population and better future utilization, the transit services should timely get re-evaluated. This study has introduced a multi-level model for optimization of bus stops. The public bus stops are categorized into three levels. Two coverage models are proposed to minimize the distance and to maximize the transit demand coverage. With minimum number of bus stop service area covered has been significantly enhanced. The unnecessary, excessive bus stops in the middle part of the city are reduced and to increase the bus accessibility in the outer area alternative bus stops are employed. The irrational bus stops in the city have been significantly minimized in the optimized system and the area where the frequency of bus stop was very low subsequently improved. Finally, the population coverage shows noteworthy growth with better accessibility to each bus stop. In future research, transit demand with respect to land use pattern can be taken into account.

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REFERENCES

[1]. Eric M. Delmelle, Shuping Li and Alan T. Murray, “Identifying bus stop redundancy: A GIS-based spatial optimization approach”, Computers, Environment and Urban Systems, Vol. 36, pp. 445–455, 2012.

[2]. Rameshwar Dayal Sharma, Sandeep Jain and Kewal Singh, “Growth rate of Motor Vehicles in India - Impact of Demographic and Economic Development”, Journal of Economic and Social Studies, Vol. 1, No. 2, July 2011.

[3]. Todd Litman, “Generated Traffic and Induced Travel Implications for Transport Planning”, Institute of Transportation Engineers, Vol. 71, No. 4, pp. 38-47, April 2001.

[4]. Transport Research Wing, Ministry of Road Transport & Highways Government of India New Delhi, “Road transport year book (2009-10 & 2010-11)” , July 2012.

[5]. Zhengdong Huang and Xuejun Liu, “A hierarchical approach to optimizing bus stop distribution in large and fast developing cities”, ISPRS International Journal of Geo-Information, Vol. 3, pp. 554-564, 2014.

[6]. A. T. Murray, “Strategic analysis of public transport coverage”, Socio-Economic Planning Sciences, Vol 35, pp. 175–188, 2001.

[7]. A. T. Murray, “A coverage model for improving public transit system accessibility and expanding access”, Annals of Operations Research, Vol. 123, pp. 143–156, 2003.

[8]. Mezyad M. Alterkawi, “A computer simulation analysis for optimizing bus stops spacing: The case of Riyadh, Saudi Arabia”, Habitat International, Vol. 30, pp. 500–508, 2006.

[9]. Ranjay M. Shrestha and Edmund J. Zolnik, “Eliminating Bus Stops: Evaluating Changes in Operations, Emissions and Coverage”, Journal of Public Transportation, Vol. 16, No. 2, 2013.

[10]. I. El-Shair, “GIS and remote sensing in urban transportation planning: A case study of Birkenhead, Auckland”, Map India Conference 2003, Transportation, 2003.

[11]. R. Sankar, J. Kavitha, & S. Karthi, “Optimization of bus stop locations using GIS as a tool for Chennai City - A case study”, Map India Conference 2003, Poster session, 2003.

[12]. Alan T. Murray, “A Coverage Model for Improving Public Transit System Accessibility and Expanding Access”, pp 1-19, June 17, 2002.

[13]. Alan T. Murray, Daoqin Tong and Kamyoung Kim, “Enhancing classic coverage location models”, International Regional Science Review, Vol 33, Issue 2, pp 115-133, April 2010.

[14]. Zhengdong Huang, “A hierarchical process for optimizing bus stop distribution”, Urban, Planning and Transport Research, Vol. 2, No. 1, 162–172, 2014.

[15]. Dhananjay B. Nalawade, Sumedh D. Kashid, Rajesh K. Dhumal, Ajay D. Nagne and Karbhari V. Kale, “Analysis of present transport system of Aurangabad city using geographic information system”, International Journal of Computer Sciences and

Engineering, Volume-3, Issue-6, pp. 124-128, June 2015.
[16]. P.G. Furth and A.B. Rahbee, “Optimal bus stop spacing through dynamic programming and geographic modeling”, Transportation Research Record, Vol. 1731, pp. 15-22, 2000.
[17]. A. A. Saka, “Model for determining optimum bus-stop spacing in urban areas”, Journal of Transportation Engineering, Vol. 127, pp. 195-199, 2001.
[18]. S. I. Chien, Z. Qin, “Optimization of bus stop locations for improving transit accessibility”, Transportation Planning Technology, Vol. 27, pp. 211–227, 2004.
[19]. Olowosegun Adebola and Okoko Enosko “Analysis of Bus-stops locations using Geographic Information System in Ibadan North L.G.A Nigeria”, Industrial Engineering Letters, Vol. 2, No. 3, 2012.
[20]. Ajay D. Nagne, Rajesh K. Dhumal, Amol D. Vibhute, Yogesh D. Rajendra, K. V. Kale and S. C. Mehrotra, “Suitable sites identification for solid waste dumping using RS and GIS approach: A case study of Aurangabad, (MS) India”, pp. 01-06, 2014.
[21]. A. Ceder, J. Prashker, H. I Stern, “An algorithm to evaluate public transportation stops for minimizing passenger walking distance”, Applied Mathematical Modelling, Vol. 7, 19–24, 1983.
[22]. J. Cheng, L Bertolini, “Measuring urban job accessibility with distance decay, competition and diversity”, Journal of Transport geography, Vol. 30, pp. 100–109, 2013.