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Determining The Capacity Using Empirical Formulas and Utilizing It to Extend the Bus Rapid Transit System – Indore Case Study

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Abstract : Bus Rapid Transit System (BRTS) is a bus-based cost-effective urban mobility that provides fast, comfortable, high quality and capacity movement of traffic in quickly expanding cities of the country. Every transit system has been designed for a certain maximum capacity which further indicates the performance of the system. This study determines the capacity of BRT System of Indore city which has a length of 11.4 km. Presently the system is operated with 56 buses with a frequency of 15 buses per hour in non-peak hours and 25 buses per hour in peak hours. The dedicated lane meant for BRT is not getting utilized to its full capacity due to a single route of BRT and rigidity of the rules. The capacity is determined using empirical formulas considering 4 critical bus stops namely Major Road 9 (MR9), Vijay Nagar, Palasia & Tantya Bhil Square (Bhawarkua) as per the present traffic load. The 4 bus stops are determined for estimation of capacity by taking data of boarding and alighting, dwell time, clearance time at the peak hour on the highest ridership day during a year. The study also determines the possible inclusion of buses from other cross routes which moves along BRTS for some distance on mixed lane. It may also be considered as an extension of the current BRT system.

Index Terms - BRT system, Feeder routes, Traffic load, Urban mobility.

I. INTRODUCTION

With the continuous development of Tier 1 cities as well as Tier-2 cities (Population range between 0.1 million to 1 million) in India, the transportation demand has gone manifold. A significant growth in the ownership of personal vehicles has been seen in last few decades in all the urban centers of India. Best alternative to personal vehicles is provision of safe, economical, rapid and convenient with novel concepts in public transport systems. Bus Rapid Transport System (BRTS) is one of the novel ideas with a comfortable fleet of buses running on a dedicated lane that attracts and encourages people to use the public transport.

Today there is a need for improvement of infrastructural facilities, such as public transportation, drinking water, waste disposal, etc. which help in providing better living conditions to the residents. One of the most important infrastructures is the development and operation of high quality rapid public transportation system. This will lead to low traffic density due to curbing of private motorization. The other advantages of low traffic density are reduced menaces like congestion, accidents, fuel consumption, environmental degradation etc.

Presently BRTS is operated regularly in many cities of India e.g., Ahmedabad, Rajkot, Jaipur, Pune, Surat, Indore etc. One of the successful BRTS is developed in Indore, the commercial capital of Madhya Pradesh and the cleanest city of India. Madhya Pradesh Government under Jawaharlal Nehru National Urban Renewal Mission (JNNURM) came up with an idea to implement the BRTS in Indore city in 2007 which becomes operational from May 2013. The details of the system will be dealt in following lines.

II. NEED OF STUDY

The 11.4 km long Bus Rapid Transit System (BRTS) of Indore City starts from Niranjanpur to Rajiv Gandhi Square having 21 bus stops including major locations such as Vijay Nagar, Major Road 9 (MR9), LIG, GPO, Palasia, Tantya Bhil Square (Bhawarkua), Rajiv Chowk etc. This system has a dedicated Bus Lane having 20 stations out of which 21 stations are located on central system. The only exception is the Palasia Bus Stop which is a kerbside station. There is a prioritized signaling system for smooth and rapid operation of busses. 14 bus stops are close to major road intersections and 7 bus stops are situated in mid-block section. The BRT system is developed on Agra-Bombay (AB) Road which provides public transport facility to the people residing on eastern part of the city (as shown in Figure 1). Presently the system is operated with 56 buses with a frequency of 15 buses per hour in non-peak hours and 25 buses per hour in peak hours. It appears from this data that the capacity of the lanes is unutilized. The utility of the lane has to be improved. The limitation of the system is that it is a single lane following old Agra Mumbai Highway. Though there exists a satisfactory footfall of passengers on the BRTS the system has not been extended since its inception. It necessitates extension of the existing BRT system to cover more areas such as the central business district, the main railway station, airport and intercity bus stations which are situated in central and western part of the city. Due to densely populated areas and congested roads on western

part of the city, it is difficult to construct the dedicated BRT system. Presently creation of new physical infrastructure for extended BRTS is not feasible but introduction of certain routes of city buses to pass through the BRT lane will enhance the utility of the BRTS. This will not only improve the connectivity but also generate facilities to utilize the BRT lane from unrepresented areas. This will be achieved through running of the busses from various feeder roads to operate on the sections of existing BRT system. This will increase the catchment area of the BRT lane and its capacity will be utilized to larger extent.

Present study is aimed at determination of the capacities of the busiest bus stations and compares it with the existing buses running per hour. Once the capacities are computed the route planning will be done to carry out the possibility of enhancement of utility by running more buses in the lane. The details of the study are reported in following paragraphs.

III. LITERATURE REVIEW

Various research scholars and practitioners of BRTS have studied various aspects of the systems and their aspects like capacity and other factors related to it. They have been briefly discussed in the text to follow. Indore city had developed a novel city bus system based on the public private partnership in the year 2003 and Indore BRTS was planned and executed in 2013 on the similar lines. This was pointed out by Sharma and Gupta (2009) they have looked at the causes that led to the formation of this model that achieves its goal of affordable and quick public transportation with regulatory control without relying on government handouts or creating a monopoly and what the model's potential flaws and strengths. They pointed that the roaring success of the model prompted and that has been replicated across the country with degree of success. Tiwari and Jain (2010) have studied the current state of BRT project in Ten Indian Cities, which are at various phases of implementation. Data for all the cities was gathered from a variety of sources, including local government websites, organizations involved in the initiatives, published papers and studies and the media. The pertinent question here is that the BRT system occupies and divides the space for the mixed traffic lanes and thus the private and other public transport users make a lot of hue and cry. Moreover, there is huge investment in creating a BRT system. If the BRT lane is not fully utilized, there is a loss to the returns on investments. Thus, there is a need for determination of the capacity of the BRT lanes at its stop to accommodate a greater number of vehicles to get passed through the BRT lane. That is the main motivation behind the present work.

The dwell time for the BRT buses is an important component for the capacity determination of the BRT. Jaiswal et al. (2010) pointed out that the classic dwell time methodology devised for suburban bus stops is commonly used to estimate bus dwell time at a Bus rapid Transit (BRT) station platform which requires correction for accommodating the effects of passengers walking on a longer BRT station platform. The average walking time of a passenger at a BRT platform is 10 times that of a normal bus stop thus there is a loss of station capacity during peak time operation. Sharma et al. (2015) have determined the capacity of Bus Rapid Transit System of Bhopal using empirical formula and micro simulation model by VISSIM software. In the empirical formula Transit capacity and quality of service manual guidelines (HCM, 2000) were followed to calculate the capacity which came out to be 41 buses per hour. In micro simulation a base network of Bhopal BRT was developed, calibrated and validated in VISSIM software. Two approaches namely failure rate approach and speed reduction approach were implemented in simulation model to estimate the bus lane capacity which came out to be 39 and 38 buses per hour, respectively. The comparison of both these indicates that TCQSM results are closer to FR approach to estimate the bus lane capacity. Al-Mudhaffar et al. (2016) determined bus stop and bus terminal capacity through HCM 2000 model and also through AASHTO (2010) Model. They have developed the capacity for Sweden where no such practice existed. They have provided a detailed procedure for capacity determination of stops and terminals and also have presented a good literature review. Dadhich, et al., (2016) focused on improving the efficiency of traffic flow on the major route by redirecting private buses, taxis, and auto rickshaws to the under-utilized BRTS corridor during peak hours, reducing congestion. However, this will reduce the capacities of the bus stops in the dedicated lane. Hisham et al. (2019) studied the performance of an on-street, mid-block, off-line bus stop by relating bus stop capacity to adjacent lane traffic volume. They used the TCQSM methodology incorporating the effect of adjacent lane traffic volume on bus stop capacity at mid-block bus stops through its effect on re-entry delay, but it does not consider the impact of the bus stop itself on adjacent lane traffic capacity. They also introduced a novel methodology to estimate the additional time required to accommodate adjacent lane traffic volume under saturated conditions. Second, the TCQSM methodology does not reflect the effect on re-entry delay of a yield-to-bus (YTB) rule, which is mandatory by law in some jurisdictions. This paper modifies the current TCQSM methodology by allowing for the YTB rule. A microscopic simulation model is developed in order to cross-validate the theoretical model developed.

IV. OBJECTIVES

The objective of the study is to determine the capacity of existing BRT system using the empirical formula provided in IRC: 124-2017, Bus Rapid Transit (BRT) – Design guidelines for Indian Cities, and Transit capacity and Quality of Service Manual (TCQSM) (2013). Also, the study is carried out to determine the possibility of inclusion of city buses running parallel to the BRT on the mixed traffic lane and planning new routes that run across the city to utilize the balance capacity for future expansion and better coverage of the BRT system.

V. METHODOLOGY

To determine the capacity of the BRT system using empirical formulas, the following steps are performed:

1) Firstly, various information is gathered regarding components of BRTs corridor such as type of BRT system, Right of Way (ROW), Station Alignment, Distance between bus stops, Number of loading areas at the bus stop etc.
2) 6 months passenger data having daily boarding and alighting details on all bus stops along with features of various busses travelling on BRTs is obtained from the governing agency i.e., Atal Indore City Transport Service Limited (AICTSL).
3) The passenger data is analyzed thoroughly to determine the 4 critical bus stops along the BRTs in both directions. Further, the peak hour of passenger demand in the morning, as well as evening, is also determined.
4) After getting the 4 critical bus stops, the field survey is carried out on each bus stop in both directions for 3 days during peak hours (both morning and evening) to collect the samples of passengers boarding, alighting, bus schedule, dwell time, clearance time, average boarding and alighting time, green cycle and total cycle time.
5) All the samples collected from the survey is compiled in various tables and graphs which are further used for the calculation of capacity.

6) After compiling, the second advanced approach based on Levinson's approach mentioned in the latest Transit capacity and quality of service manual (TCQSM) 2013 and IRC:124-2017 – Bus Rapid Transit (BRT) – Design guidelines for Indian Cities is used to calculate the capacity of each critical bus stop in each direction.

7) The capacity of each bus stop is determined and conclusions are made from the analysis.

8) Various new routes are determined which can be proposed to utilize the balance capacity of underutilized bus stops.

VI. ANALYSIS

6 monthly (September 2019 to March 2020) passenger riding data was analyzed and it was found that around 8 lac people had travelled on the BRT system. The analysis shows that Palasia, Tantya Bhil Square (Bhawarkua), Vijay Nagar & MR9 are most critical bus stops on which maximum passengers boarded and alighted [as shown in Figure 1] during the peak hours i.e., 9 AM TO 10 AM and 7 PM to 8 PM [as shown in Figure 2].

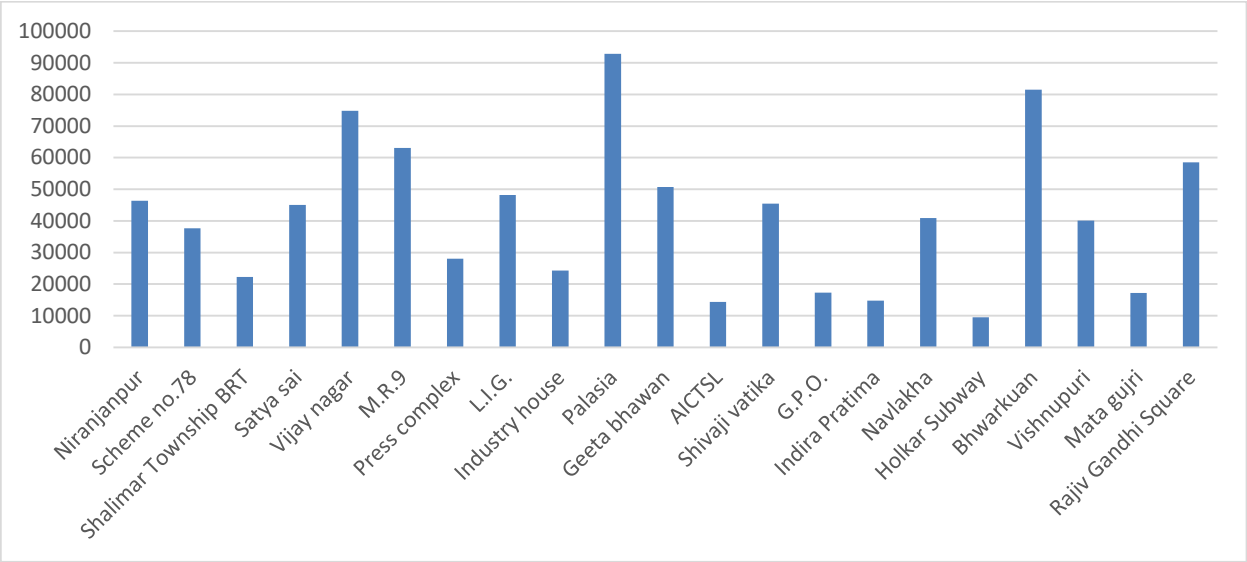

figure 1: graph showing variation of passengers at various bus stops

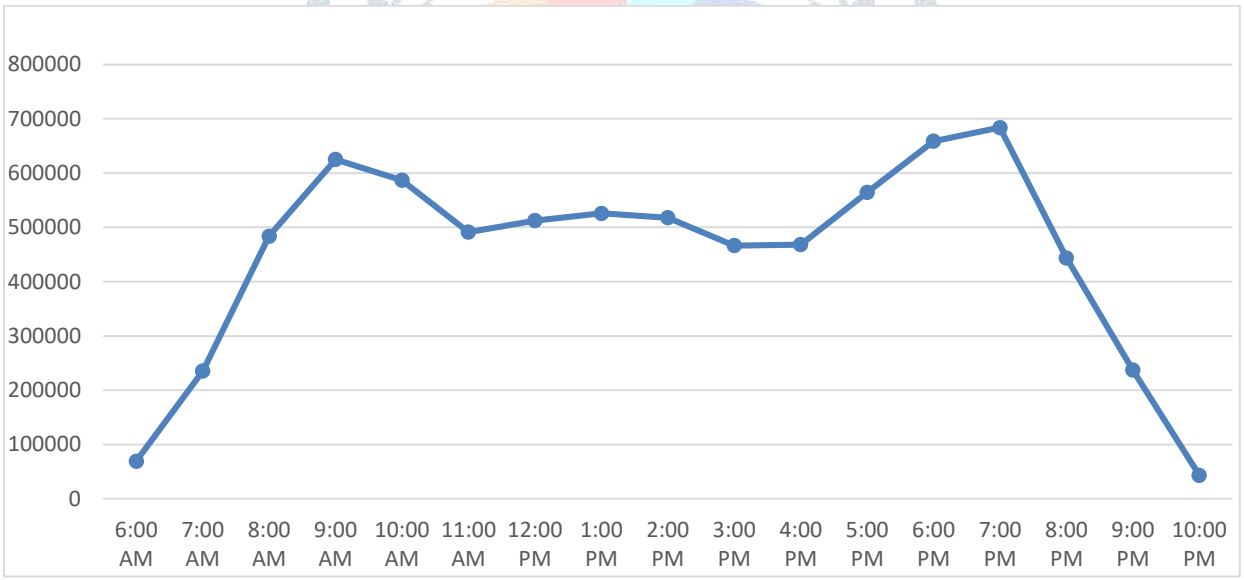

figure 2: graph showing hourly variation of passengers at various bus stops

table 1: green signal time and total cycle time (in sec)

	Vijay Nagar	MR9	Palasia	Tantya Bhil Square (Bhawarkua)
Green Signal Time	35	24	40	35
Total Cycle Time	105	84	150	150
g/C ratio	0.33	0.29	0.27	0.23

table 2: average dwell time, clearance time (in sec)

	Vijay Nagar	MR9	Palasia	Tantya Bhil Square (Bhawarkua)
Average Dwell Time	221	121	314	111
Clearance Time	8	6	8	6

table 3 frequency of bus and details of boarding and alighting passengers

	Vijay Nagar	MR9	Palasia	Tantya Bhil Square (Bhawarkua)
Frequency of Bus	15	15	13	16
Avg. No. of Boarding	14	10	16	10
Avg. No. of Alighting	12	10	18	11
Avg. Time for Boarding	8	5	8	5
Avg. Time for Alighting	5	6	8	5

Further, after putting all the above parameters in the empirical formula provided in the second advanced approach based on Levinson's approach mentioned in the latest Transit capacity and quality of service manual (TCQSM) 2013 and IRC:124-2017 – Bus Rapid Transit (BRT) – Design guidelines for Indian Cities, which is as follows: -

$$B_s = Nel \times \frac{3600\,(\frac{g}{C})}{t_c + t_d(\frac{g}{C}) + ZC_v t_d}$$

Where.,

B_s = Bus Stop Capacity

Nel = Number of Effective Loading Area

t_d = Average Dwell Time (Sec)

t_c = Average Clearance Time (Sec)

g = Green Signal Time (Sec)

C = Total Cycle Time (Sec)

Z = Depends upon Failure Rate (for Max. Capacity, Failure rate = 25%)

t_d = Coefficient of Variation

VII. RESULTS

Capacity of Critical Bus Stops				
Route	**Station**	**Time**		**Capacity**
Niranjanpur to Rajiv Chowk	Vijay Nagar	9 AM to 10 AM	17	17
		7 PM to 8 PM	18	
	MR9	9 AM to 10 AM	34	36
		7 PM to 8 PM	37	
	Palasia	9 AM to 10 AM	15	16

		7 PM to 8 PM	17	
	Tantya Bhil Square (Bhawarkua)	9 AM to 10 AM	29	30
		7 PM to 8 PM	31	
Rajiv Chowk to Niranjanpur	Vijay Nagar	9 AM to 10 AM	21	22
		7 PM to 8 PM	24	
	MR9	9 AM to 10 AM	28	29
		7 PM to 8 PM	31	
	Palasia	9 AM to 10 AM	12	13
		7 PM to 8 PM	14	
	Tantya Bhil Square (Bhawarkua)	9 AM to 10 AM	36	35
		7 PM to 8 PM	34	

Since, the BRT system is running under-utilized, therefore few routes have been determined on which buses are travelling along/parallel to BRTs which can be accommodate are as follows:

S.No	Route No.	Route Name	Bus Type	Section of BRTS that can be utilize
1	M-17	Toll Naka to Railway Station	MIDI	Dewas Naka to Vijay Nagar
2	M-22	Sarwate Bus Depot to Lakhani Bypass	MIDI	Navlakha to MY Hospital Bus Stand
3	M-25	Rajwada to Nariman Point	MIDI	Vijay Nagar to Bombay Hospital
4	M-26A	Sanwer to Indore Railway Station	MIDI	Dewas Naka to Vijay Nagar
5	R-4	Dewas Naka to Reti Mandi	NON-AC	Dewas Naka to Vijay Nagar
6	R-11	Tejaji Nagar to Gandhi Nagar	NON-AC	Bhawarkua to White Church
7	R-5	Mhow Naka To Aurbindo	NON-AC	Bhawarkua to Choithram Mandi & Vijay Nagar to Bombay Hospital

VIII. CONCLUSION

From the study of the capacity of the BRT system it is concluded that there are many stops that are having enough capacities but the number of buses travelling in the BRTS are very less. Thus, there is a need to enhance the traffic of buses in the BRT lanes in a few sections. In the following lines the stop wise findings are provided.

1) The Palasia bus station is the only kerb side station on BRTs having least capacity as compared to other stops. Since this is not situated on a separated lane the mixed traffic conditions affect the bus movement. The reasons being the location of the stop adds re-entry delay to the clearance time and also the bus manoeuvres in the mixed traffic lane. Moreover, there is a weaving traffic at exit and entry of the buses to the BRT lane.

2) Capacity is comparatively more for stops which are near side i.e., where stops are just before an intersection. In the far side stop the capacity is slightly less. There appears to be change in capacity and increase the capacity of buses.

3) The Vijay Nagar stop which has two intersections needs better signal synchronization. The other option to reduce the menace is to extend the BRT lane on Rasoma inter section and plan a one-way entry through the Rasoma end. The right turning traffic from Vijay Nagar towards Patnipura and Malwa Mill can be diverted through Vijay Nagar square only.

4) After analyzing the capacity, it is concluded that flow of more buses in the BRT lane is possible as the number of buses running are less than the capacity of bus stops. Hence, the buses running parallel/along in some sections of BRTs can be accommodate so that the capacity of bus stop can be utilized.

5) Also, new routes can also be proposed to use the various section of BRTs taking advantage of under-utilized bus stops.

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