IRC:124-2017

BUS RAPID TRANSIT (BRT) DESIGN GUIDELINES FOR INDIAN CITIES

INDIAN ROADS CONGRESS
2017

BUS RAPID TRANSIT (BRT) DESIGN GUIDELINES FOR INDIAN CITIES

Published by:

INDIAN ROADS CONGRESS

Kama Koti Marg,
Sector-6, R.K. Puram,
New Delhi-110 022

NOVEMBER, 2017

Price : ₹ 600/-
(Plus Packing & Postage)

IRC:124-2017

First Published : November, 2017

Printed at India Offset Press, Delhi - 110 064
500 Copies

CONTENTS

S. No.	Description		Page No.
Personnel of the Highways Specifications and Standards Committee			i-ii
Abbreviations			iii
Definitions			iv
Introduction			1
1.	Bus Rapid Transit System (BRT)		2
2.	Role of BRT		4
	2.1	Forms of Road-Based Public Transport with Priority	4
	2.2	Light Rail Transit (LRT)	10
	2.3	BRT vs. Road Expansion	11
	2.4	BRT and Grade-Separated Rail	12
3.	Planning for BRT		14
	3.1	Network Selection	14
	3.2	BRT Configuration and System Capacity	17
4.	System Design		19
	4.1	Dedicated Bus Lane Alignment	19
	4.2	Station Alignment	19
	4.3	Calculating Corridor Capacity: Basic Approach	22
	4.4	Station Saturation	23
	4.5	Calculating Corridor Capacity	24
5.	Station Design		27
	5.1	Bus-Station Interface	27
	5.2	Station Layout and Size	31
	5.3	Distance between Stations	33
	5.4	Architectural Features	33
	5.5	Terminal Design	34
6.	Corridor Design		36
	6.1	Street Elements and Design Configurations	36
	6.2	Intersection Design	45
	6.3	Corridor Management	49
	6.4	BRT Corridor Designs for Special Cases	50
	6.5	Pavement Design	51
7.	Universal Accessibility		52
	7.1	Footpaths	52
	7.2	Pedestrian Infrastructure	54

7.3	Passenger Access	54
7.4	Station Ramps	56
7.5	Bus Interior	57
7.6	Bus Stops on Service Extensions	58
8.	Vehicle Specifications	58
9.	Safety	61
10.	BRT Operations	63
10.1	System Monitoring	63
10.2	Fare Collection	64
10.3	Passenger Information	66
10.4	Fleet Management and Scheduling	67
11.	Inter-Modal Integration	68
12.	Depot Layout Design	68
13.	Parking Management	70
14.	System Evaluation	71
14.1	Design Evaluation	71
14.2	Performance Evaluation	73
15.	Checklist for BRT Infrastructure and Operations Management	74
16.	Care to be taken while Implementing BRT	76
16.1	Network Length	76
16.2	Dedicated High Quality Fleet	76
16.3	BRT Lane and not a Bus Lane	76
16.4	BRT Station Location	76
16.5	Median Alignment of BRT Lanes	76
16.6	Intersection Design	77
16.7	Overlap with Rail-Based Mass Transit Systems	77
16.8	Bus Operations Monitoring	77
16.9	BRT Fleet Expansion	77
16.10	Interdepartmental Coordination	78
16.11	Supporting Infrastructure	78
16.12	Fund Allocation	78
16.13	Skilled Manpower	78
17.	Comparison of Various Systems Across Parameters	79
References		80

PERSONNEL OF THE HIGHWAYS SPECIFICATIONS AND STANDARDS COMMITTEE

(As on 23.06.2017)

1	Kumar, Manoj (Convenor)	Director General (Road Development) & Special Secretary to Govt. of India, Ministry of Road Transport and Highways, New Delhi
2	Singh, B.N. (Co-Convenor)	Addl. Director General (Incharge), Ministry of Road Transport and Highways, New Delhi
3	Verma, Dr. S.K. (Member Secretary)	Chief Engineer (R) S,R & T, Ministry of Road Transport & Highways, New Delhi
		Members
4	Bamezai, Prof. (Dr.) Gita	R&D, Indian Institute of Mass Communication, New Delhi
5	Basar, Toli	Chief Engineer, PWD, Arunachal Pradesh
6	Bhanot, Balraj	Chairman, TED, Bureau of Indian Standards, New Delhi
7	Bongirwar, P.L.	Secretary (Retd.), PWD Maharashtra
8	Gupta, D.P.	DG(RD) & AS (Retd.), Ministry of Road Transport and Highways, New Delhi
9	Jain, Prof. (Dr.) S.S.	Professor, Indian Institute of Technology, Roorkee
10	Jain, R.K.	Chief Engineer (Retd.), PWD Haryana
11	Kadiyali, Dr. L.R.	Chief Executive, L.R. Kadiyali & Associates, New Delhi (*Expired on 18.02.2016*)
12	Lal, Bhure	Chairman, Environment Pollution Control Authority, Delhi
13	Lal, Chaman	Engineer-in-Chief, Gurugram Metropolitan Development Authority, Haryana
14	Narain, Sunita	DG, Centre for Science and Environment, New Delhi
15	Nashikkar, J.T.	Secretary (Retd.), PWD Maharashtra
16	Pandey, R.K.	Member (Projects), National Highways Authority of India, New Delhi
17	Parida, Prof. (Dr.) M.	Dean, SRIC, Indian Institute of Technology, Roorkee
18	Pateriya, Dr. I.K.	Director (Tech), National Rural Roads Development Agency, New Delhi
19	Pawar, Ajit	Secretary (Retd.), PWD Maharashtra
20	Porwal, Dr. S.S. (VSM)	ADG (Retd.), Border Roads Organisation, New Delhi
21	Raju, Dr. G.V.S.	Engineer-in-Chief (Retd.), Roads & Building, Andhra Pradesh
22	Rawat, M.S.	Executive Director, AECOM India Pvt. Ltd.
23	Sarangi, D.	CGM, National Highways Authority of India, New Delhi
24	Sharma, M.P.	Chief Engineer, Ministry of Road Transport and Highways, New Delhi
25	Sharma, S.C.	DG(RD) & SS (Retd.), Ministry of Road Transport and Highways, New Delhi

26	Sheokand, Balbir Singh	Executive Engineer, PWD Haryana
27	Singh, Nirmaljit	DG(RD) & SS (Retd.), Ministry of Road Transport and Highways, New Delhi
28	Singh, Pawan Kumar	GM, 3M India Ltd.
29	Sinha, A.V.	DG(RD) & SS (Retd.), Ministry of Road Transport and Highways, New Delhi
30	Tawade, D.O.	Member (T), National Highways Authority of India, New Delhi
31	The Director, (Chandra, Dr. Satish)	Central Road Research Institute, New Delhi
32	The Director General, (Shrivastava, Lt. Gen. S.K.)	Border Roads Organisation, New Delhi
33	The Director General, (Mathur, Vishnu)	Society of Indian Automobile Manufacturers, New Delhi
34	The Engineer-in-Chief, (Sharma, Lt. Gen. Suresh)	Military Engineer Services, New Delhi
35	Tickoo, Bimal	Secretary (T), PWD Jammu
36	Tiwari, Prof. (Dr.) Geetam	Professor, Indian Institute of Technology, New Delhi
37	Varshney, Sharad	Superintending Engineer, Ministry of Road Transport and Highways, New Delhi
38	Verma, G.L.	MD, Engg and Planning Consultants Ltd., New Delhi

Corresponding Members

1	Baluja, Dr. Rohit	President, Institute of Road Traffic Education, New Delhi
2	Bhowmik, Sunil	Engineer-in-Chief (Retd.), Tripura
3	Kandasamy, C	DG(RD) & SS (Retd.), Ministry of Road Transport and Highways, New Delhi
4	The Director, (Patil, Capt. (Dr.) Rajendra B. Saner)	Central Institute of Road Transport, Pune

Ex-Officio Members

1	President, Indian Roads Congress	(Pradhan, N.K.), Engineer-in-Chief cum Secretary, Works Department, Odisha
2	Director General (Road Development) & Special Secretary to Govt. of India	(Kumar, Manoj), Ministry of Road Transport and Highways, New Delhi
3	Secretary General, Indian Roads Congress	Nirmal, Sanjay Kumar

ABBREVIATIONS

BA	Boarding-Alighting
BLT	Bus Lost Time
BRT	Bus Rapid Transit
FO	Frequency-Occupancy
ITS	Information Technology Systems
LRT	Light Rail Transit
MOHUA	Ministry of Housing and Urban Affairs
MRT	Mass Rapid Transit
MV	Motorized Vehicles
PIS	Passenger Information System
pphpd	Passengers Per Hour Per Direction
RFID	Radio Frequency Identification
ROW	Right of Way
SPV	Special Purpose Vehicle
UBS	Urban Bus Specification

DEFINITIONS

Bunching: Unintended arrival of two or more public transport vehicles in close succession, often occurring when vehicles operate at high frequencies and/or in mixed-traffic.

Bus Rapid Transit (BRT): A high-quality bus-based transit system that delivers fast, comfortable, and cost-effective urban mobility through the provision of segregated right- of-way infrastructure, rapid and frequent operations, and excellence in marketing and customer service.

Busways: A dedicated lane for existing bus services without any level boarding on low floor buses, SMART fare collection, information display etc. (See also closed and hybrid BRT system.)

Closed BRT system: Service by buses that operate only in exclusive busways, complemented by feeder service to trunk stations or terminals. (See also hybrid BRT system)

Dedicated lane: A lane in which entry is permitted for specific types of vehicles.

Depot: A facility with provision for bus cleaning, maintenance, and parking. Depots also offer office space for bus operators and facilities for drivers including washrooms, canteens, and rest areas.

Docking bays: A location in a BRT station where a bus stops and aligns to the boarding platform.

Dwell time: The amount of time that a vehicle occupies a given stopping bay.

Expressway: A divided highway for through traffic with access control and grade separations at most intersections.

Frequency: Number of vehicles per hour that stop at a station.

Headway: Length of time that elapses between vehicle arrivals at a stop or station.

Hybrid system: Service that directly links origins and destinations with buses that operates both on and off an exclusive busway. (See also closed BRT system)

Light Rail Transit (LRT): Electric rail-based technology operated at surface level in exclusive lanes, typically composed of a single rail car or as a short train of cars.

Load factor: The ratio of the number of passengers on a vehicle to the vehicle's capacity. For example, if a bus has a capacity of 70 and an average load of 60 passengers, then the load factor is 0.85. The load factor for a BRT system is determined by the frequency of vehicles and the passenger volume. Higher load factors are more profitable for the system but may result in overcrowding.

Median bus lanes: Lanes reserved for buses that are aligned in the middle of a roadway.

Mixed traffic lane: A lane designated for use by various types of vehicles and users.

Passengers per hour per direction (pphpd): The number of passengers passing by a particular point in a single direction every hour.

Passing lanes: Additional bus lane at the station for a given direction of travel that allows buses to pass (overtake) stopped buses.

Platform: An area in a BRT station where passengers board and alight from buses. Platforms also accommodate passenger waiting and circulation.

Ramp: An inclined walkway or roadway connecting elements at different levels.

Saturation: Percentage of time that a station bay is occupied.

Sub-stop: Distinct stops within a single station,placed adequately apart to allow simultaneous, independent access to BRT buses via passing lanes.

BUS RAPID TRANSIT (BRT) DESIGN GUIDELINES FOR INDIAN CITIES

INTRODUCTION

At the first meeting of the H-8 Committee on Urban Roads and Streets held on 20th May 2015, members expressed the view that several cities in the country would require strengthening of road-based public transport and high capacity bus transport in corridors exhibiting heavy demand for public transport. In that context, the Committee decided that design guidelines may be prepared in respect of Bus Rapid Transit. This would help the city authorities in planning, provision and operations of this mode of travel, where warranted based on existing and projected demand.

Accordingly, the Committee constituted a Sub-Group headed by Ms. Shreya Gadepalli, Member of the Committee and South Asia Programme Lead, Institute for Transportation and Development Policy, to undertake the task of preparing the document on BRT Design Guidelines. Other members of the Sub-Group were Dr. Manoranjan Parida, Professor Transportation Division, IIT Roorkee; Dr. Devesh Tiwari, Principal Scientist, CRRI; Dr. Ch. Ravi Sekhar, Principal Scientist, CRRI; Mr. Amit Bhatt of World Resources Institute (WRI) and Ms. Anjlee Agarwal, Samarthyam, India. In addition, Mr. Christopher Kost and Ms. Pranjali Deshpande-Agashe from Urban Works Institute provided support to the Sub-Group.

The Sub-Group prepared the draft document, which was circulated among members of the Committee for comments and feedback. The document was further revised in the light of guidance and comments provided by the Committee.

The H-8 Committee in its meeting held on 28.10.2015 approved the BRT Design Guidelines and recommended its submission to the Highway Specifications and Standards Committee for their consideration and approval.

The composition of the H-8 Committee is given below:

Nath, Prem	Surisetti, Ramakrishna
Ram, Prof. (Dr.) Sewa	Tiwari, Prof. (Dr.) Geetam
Ravi Sekhar, Dr. Ch.	

Corresponding Members

Kharwadkar, V.	Prasad, R. Jai
Krishnan, Dr. Geeta	Ramchandani, S.M.

Ex-Officio Members

President, Indian Roads Congress	(Pradhan, N.K.), Engineer-in-Chief cum Secretary, Works Department, Odisha
Director General (Road Development) & Special Secretary to Govt. of India	(Kumar, Manoj), Ministry of Road Transport & Highways
Secretary General, Indian Roads Congress	Nirmal, Sanjay Kumar

The Highways Specifications & Standards Committee (HSS) considered and approved the draft document in its meeting held on 23rd June, 2017. The Executive Committee in its meeting held on 13th July, 2017 considered and approved the same document for placing it before the Council. The Council in its 212th meeting held at Udaipur on 14th July, 2017 considered and approved the draft IRC:124-2017 “Bus Rapid Transit (BRT) Design Guidelines for Indian Cities” for printing.

1. BUS RAPID TRANSIT SYSTEM (BRT)

Bus Rapid Transit (BRT) is a high quality bus-based transit system that delivers fast, comfortable, and cost-effective urban mobility through the provision of segregated right-of-way infrastructure, rapid and frequent operations, and excellence in marketing and customer service. The United States Federal Transit Administration (FTA) defines BRT as a “rapid mode of transportation that combines the quality of rail transit and the flexibility of buses.” (Thomas 2001)

A more detailed definition, which was developed as part of the Transit Cooperative Research Program (TCRP)[1] A-23 project, is:

---

1 TCRP is a cooperative effort of three organizations: the Federal Transit Administration (FTA); the National Academies, acting through the Transportation Research Board (TRB); and the Transit Development Corporation, Inc. (TDC), a nonprofit educational and research organization established by the American Public Transportation Association (APTA). For more information, visit www.tcrponline.org.

BRT is a flexible, rubber-tired rapid transit mode that combines stations, vehicles, services, running way, and Intelligent Transport System (ITS) elements into an integrated system with a strong positive image and identity. BRT applications are designed to be appropriate to the market they serve and their physical surroundings and can be incrementally implemented in a variety of environments.

In brief, BRT is a permanently integrated system of facilities, services, and amenities that collectively improve the speed, reliability, and identity of bus transit. In many respects, BRT is rubber-tired Light Rail Transit (LRT), but with greater operating flexibility and potentially lower capital and operating costs. (Levinson et al, 2002)

The success of BRT depends on sound corridor selection and a set of physical and operational elements that improve the speed of operations, increase capacity, and enhance safety. These elements include the following:

- Dedicated median bus lanes that are physically separated from mixed traffic lanes. Dedicated lanes are crucial for ensuring that buses can move quickly and avoid congestion.
- A dedicated fleet of high quality buses and high quality stations with platforms that match the level of the bus so that passengers can enter and exit quickly and easily without climbing steps.
- Smart fare collection to enhance passenger convenience and improve efficiency.
- Well-designed intersections that restrict mixed traffic from taking turns across the bus way.

Dedicated Right-of-Way Bus-only lanes fully segregated from mixed traffic	**Busway Alignment** Bus-only lanes aligned to the middle, not the curb, of a road	**off-board fare Collection** Turnstile-controlled or proof-of-payment fare collection system	**Intersection Treatments** Mixed-traffic is prohibited from making turns across the busway	**Platform-Level Boarding** Station platforms level with bus floors when boarding and alighting

Fig. 1: Basic elements of BRT

Much like a modern metro rail system, high quality BRT systems adopt an ecosystem approach where all elements including rolling stock (buses), stations, terminals, passenger information, and fare collection are designed to function seamlessly with each other. The coordinated provision of these elements is critical to maintaining superior performance and excellent customer service. Integration of these features accounts for proven track record of BRT systems in not only serving existing public transport users better but also attracting users from personal motor vehicles.

An efficient street-level BRT can:

- Result in a multi-fold increase in the people-carrying capacity of urban roads.
- Serve a wide range of demand from 2000 to 45,000 persons per hour per direction (pphpd) at a capital cost that is typically one-tenth of elevated rail system to one-twentieth of an underground rail system.
- Be implemented quickly, in a span of three to five years.
- Cause a mode shift from personal motor vehicles to public transport.[2]
- Reduce emissions of harmful local pollution and greenhouse gases by attracting passengers from more polluting modes.

2. ROLE OF BRT

2.1 Forms of Road-Based Public Transport with Priority

Road-based public transport priority in urban areas can take a variety of forms, ranging from simple kerbside bus lanes to high capacity BRT and Light Rail Transit (LRT) corridors. Each of these approaches and technologies can have a role to play, depending on travel patterns, expected level of demand, and available capital budget. However, cities should exercise caution when planning for high-demand corridors, as basic solutions such as kerbside bus lanes or busways will provide a below average level of service.

Within these categories, BRT can be further classified into two typologies: “closed” or “hybrid” systems. BRT systems, whether closed or hybrid, share key features, such as dedicated median lanes, level boarding, and off-board ticketing. However, BRT systems differ in how they provide service beyond dedicated trunk corridors. While closed systems operate feeder services with separate vehicles, hybrid systems extend trunk services beyond dedicated corridors, providing direct service with the same vehicle.

2.1.1 *Bus lanes*

Bus lanes typically consist of painted demarcations on the kerbside of a carriageway. Buses stop at normal bus shelters along the side of the road. Personal motor vehicles are generally restricted from using the bus lanes, but may enter the lanes to access properties and to make left turns.

Well-enforced kerbside bus lanes may offer a modest speed improvement over mixed traffic bus operations. However, kerbside lanes experience several drawbacks:

---

2 Indian BRT systems like Janmarg (Ahmedabad) and Rainbow (Pune) have experienced mode shift around 8-12% during the initial period.

- Lack of physical delineation makes it difficult to prevent unauthorised entry into the bus lane.
- Frequent entry of vehicles making left turns into properties or side streets can slow down buses.
- Personal and delivery vehicles may use the bus lanes for parking and drop-off.
- Stepped entry increases boarding and alighting times and makes the system less accessible.
- High bus speeds adjacent to the footpath pose a safety hazard for pedestrians.
- At intersections, mixed traffic turning left comes into conflict with buses moving straight.
- Kerbside bus lanes require a more generous kerb radius at intersections, in case buses have to make left turns. This increases accident risk at intersections, especially for pedestrians.
- Unless physically separated cycle tracks are provided, cyclists are forced to travel in the bus lane next to fast-moving vehicles. Besides compromising cyclist safety, this arrangement also slows down buses.

Cities such as London, Sao Paulo, and Singapore have created networks of kerbside bus-only lanes. These lanes are somewhat useful at raising bus speeds when effectively enforced and paired with congestion pricing, parking control, or other measures to reduce personal motor vehicle traffic. However, in cities where enforcement and travel demand management measures are weak, the benefit of painted bus lanes is marginal. Buses tend to leave the bus lanes for mixed traffic lanes in order to avoid parked vehicles and slow moving traffic. The capacity as well as speed of buses on such lanes tends to be low.

Photo 1: Parked vehicles and standing delivery trucks can compromise the utility of kerbside bus lanes (left): New York City, USA. Mixed traffic turning movements can also block kerbside lanes, leading to slower bus speeds (right): Los Angeles, USA.

2.1.2 *Busways*

Busways give existing city buses priority with dedicated lanes, often in the median. The dedicated lanes may contribute to modest savings in travel time. However, busways miss many of the benefits of a mass rapid transit system.

Elements that typically signify a busway are:

- Focus is on physical infrastructure (e.g., dedicated bus lanes), with less attention given to the overall ecosystem (e.g., seamless interface between stations and buses, route rationalisation, passenger information, electronic fare collection, intersection priority, and Information Technology Systems [ITS]).
- Buses of varying configurations (i.e., in length, position of doors, size of doors, floor height, and presence of steps) operate on the dedicated bus lanes. Poor docking at stations, narrow doors, and steps make boarding or alighting inconvenient and slow, lead to higher dwell times at stations and longer journey times for passengers.
- When bus lanes are located on the kerbside of a road, they face constant interruption from vehicles making left turns into adjacent properties and side streets.
- Kerbside lanes tend to be encroached by parked vehicles. They also introduce the risk of conflicts between pedestrians and buses if pedestrian traffic spills over into the busway. All of these conflicts reduce safety and inhibit system speed, making the system less attractive for customers. They also limit the overall capacity of the corridor.
- Little effort is made to train bus drivers on correct docking and safe driving.
- Retention of existing operator(s) running the same routes that they did previously and lack of route rationalisation can result in higher than necessary bus frequencies and long dwell times that potentially choke the busway.
- Operational interruptions are caused by frequent breakdowns of old buses in the busway.
- Old, cash-based ticketing inside buses (rather than cashless ticketing, primarily at the station), potentially lead to inconvenience to passengers and operational delays.
- Lack of comprehensive branding and customer information, along with the poor image of existing buses that operate in the lanes, make the system unattractive to potential customers.

While many cities in the world have attempted to create basic busways, the experience of passengers has not been significantly different from that in regular bus services in the city. Some cities, like Bogotá (Colombia) and Lima (Peru), started with busways but rebuilt those corridors as part of a BRT system to overcome the low quality of service, long travel times, and poor image of the busways. While the original busways had high throughput (exceeding 20,000 pphpd in some cases), commercial speeds were often below 10 km/h.

Photo 2: A lack of level boarding and on-board fare collection in Seoul, South Korea (left) and Dalian, China (right) leads to higher boarding times.

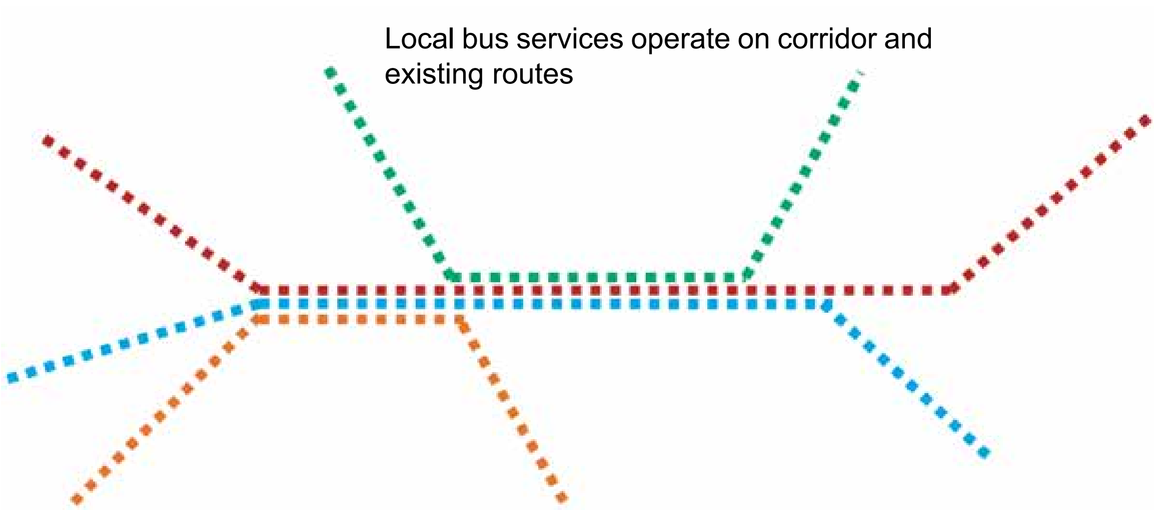


Fig. 2: Busways provide dedicated lanes for buses but are often characterised by the lack of a dedicated bus fleet, poor quality stops, on-board ticketing, complicated route structures, and limited branding.

2.1.3 *Closed BRT systems*

Closed BRT systems tend to mimic rail-based mass rapid transit systems. Key elements of a closed system are:

- Specially designed trunk buses that operate only on dedicated BRT lanes.
- Separate trunk and feeder routes that connect at terminal stations. This typically reduces the fleet required. While it increases the number of passenger transfers, the financial performance of the system improves due to better operational efficiency.

- Fare collection at the stations to reduce boarding and alighting delays, improve system efficiency, and enhance passenger convenience.

Compared to kerbside bus lanes and busways, BRT corridors add design elements that lead to a significant increase in capacity. In particular, passengers can board and alight through multiple wide doors without internal steps. Level boarding reduces the time that buses need to stop at each station, allowing a corridor to handle a larger number of buses each hour. In addition, off-board fare collection reduces delays caused by fare collection and payment verification inside the bus. Together, these design features enable BRT systems to handle high passenger throughput—ranging from 12,000 pphpd with a single lane per direction to 45,000 pphpd with passing lanes—often with commercial speeds of 20 km/h and above. (See Section 4.3).

Bus operation reforms typically accompany the implementation of closed BRT systems. Often, the private sector is contracted to provide day-to-day services for various elements including bus operations, fare collection, system maintenance, and security.

While closed BRT systems are similar to metro systems in many respects, a key difference is that BRT systems allow flexible routing—services can combine two or more trunk corridors, thereby reducing the number of transfers compared to a metro system in which passengers must interchange between lines. However, closed BRT systems tend to have more transfers than busways and regular city bus services due to the trunk-feeder configuration.

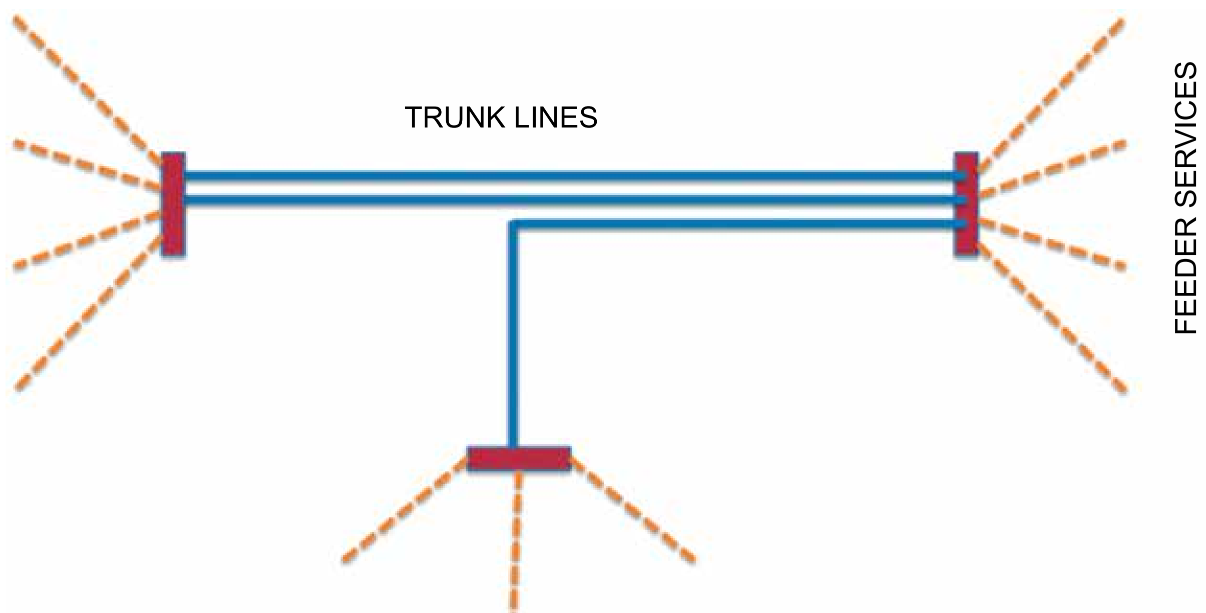


Fig. 3: Routes in a closed system are rationalised to operate as trunk and feeder services, where only BRT vehicles operate on the trunk corridor.

Photo 3: Many Latin American BRT systems, including Quito, Ecuador (left) and Bogotá, Colombia (right), operate as closed systems.

Closed systems can be employed when the demand is very high on trunk corridors but declines significantly on the feeder branches. Services within the trunk corridor are highly efficient and punctual since they are almost unaffected by the remaining traffic. Passenger transfers between trunk and feeder services should be facilitated with efficient interchange terminals to mitigate the inconvenience to the transferring passengers. Such transfer terminals may require differential platform heights in order to provide level boarding to feeder as well as trunk buses.

2.1.4 *Hybrid BRT systems*

Hybrid BRT systems combine the benefits of closed BRT system with the flexibility of busways. The routes operated by the BRT fleet extend beyond the network of dedicated corridors, thereby providing passengers with direct connections and reducing the need for transfers. Otherwise known as "direct services," these extended routes are most effective if the extended portion of the route is relatively short and uncongested. Otherwise, delays on the service extensions can result in irregular bus arrivals once buses enter the BRT trunk corridor.

Recognising the potential for improved customer service from hybrid configurations, many BRT systems even those that began as closed trunk-and-feeder systems have begun introducing direct services. BRT systems with hybrid services include the Guangzhou BRT (Guangzhou, China), Rainbow BRT (Pune-Pimpri Chinchwad, India), and Rea Vaya BRT (Johannesburg, South Africa). Hybrid systems can have a wide range of capacities from 2,000 pphpd to 30,000 pphpd at commercial speeds of around 20 km/h.

While some hybrid systems retain the existing bus route network and simply operate those routes in the new physical infrastructure of the BRT network, the introduction of BRT presents an opportunity to improve customer experiences by rationalising the routes. Rationalisation can simplify complicated route networks, reduce wait times, and minimise the number of passengers who need to transfer one or more times in order to reach their destinations. The rationalisation process should be informed by the data obtained from travel demand surveys (see Section 3.1, Corridor Selection).

Photo 4: The Janmarg system (Ahmedabad, India) has doors on either side of the BRT bus to serve passengers in the corridor as well as in feeder areas. The high floor buses are not commuter friendly outside the corridor.

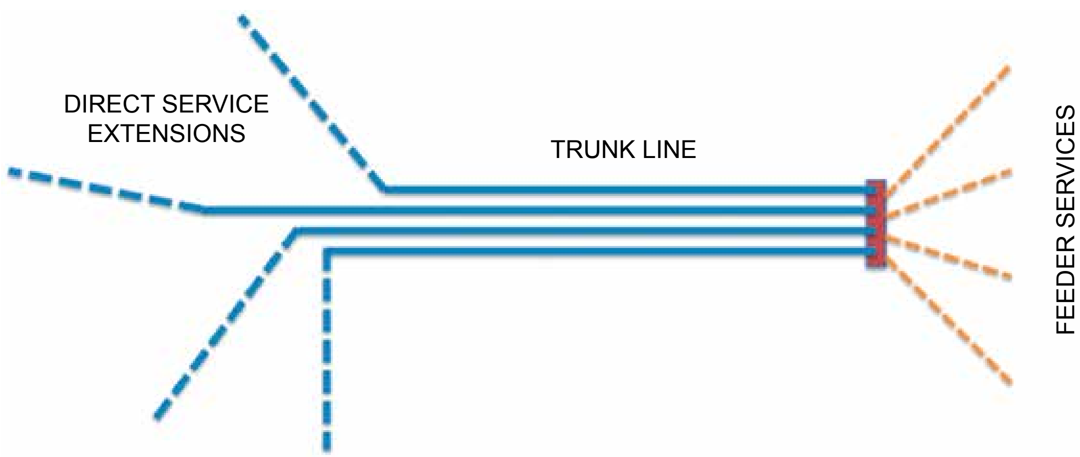


Fig. 4: In a hybrid BRT system, BRT buses operate in the trunk line corridor as well as the feeder area, thereby reducing the need for passenger transfers.

2.2 Light Rail Transit (LRT)

LRT is an electric rail-based technology operating either as a single rail car or as a short train of cars, typically on an exclusive right-of-way at street level. Modern LRT systems feature many of the same features as BRT, including platform level boarding, off-board fare collection, and real-time passenger information.

Surface LRT systems usually carry volumes below 15,000 pphpd. As volumes increase, the only option is to increase the service frequency or increase the number of cars in the train. LRT systems generally cannot accommodate passing tracks, so system capacity is limited to the number of people that single track can serve. Operations are restricted to the network of LRT tracks, akin to a closed BRT system. Surface LRT systems cost 8 to 10 times as much as BRT systems. Therefore, for most urban corridors, either a closed or hybrid BRT system is more cost-effective than LRT. **Table-1** summarises the typical features of road-based public transport priority systems.

Table 1: Typical Features of Road-Based Public Transport Priority Systems

	Kerbside bus lanes	**Busways**	**Closed BRT systems**	**Hybrid BRT systems**
Physically separated corridor	-	Recommended	Recommended	Recommended
Dedicated fleet	-	-	Recommended	Recommended
Platform-level boarding for the entire fleet	-	-	Recommended	Recommended
Real-time passenger information	-	-	Recommended	Recommended
Off-board fare collection	-	-	Desirable	Desirable
Service extensions beyond trunk corridor	Recommended	Recommended	-	Recommended
Feeder services	-	-	Desirable	Desirable
Bus floor height	Multiple heights	Multiple heights	Low or high	Preferably low

2.3 BRT vs. Road Expansion

Cities often try to address congestion by building wider roads, flyovers, and elevated roads. Such investments in car-centric infrastructure bring at best short-lived mobility benefits, as private cars are inefficient users of precious road space.

A single lane filled with cars typically carries only 1,000 to 1,200 pphpd, compared to 2,000-12,000 pphpd in a single BRT lane.[3] In the long run, studies have found that there is a near one-to-one relationship between expansion in road space and the ensuing road congestion[4], i.e., more and more people shift to a new road until they have used up all of the additional road space. As a result, speeds plummet to the same level experienced prior to the road expansion project but with a larger number of vehicles stuck in traffic.

The only way to achieve a lasting increase in the capacity of the transport system of a city is to invest in modes that use road space efficiently namely public transport, walking, and cycling. Cities should devote a major share of transport funding to cost-effective sustainable transport infrastructure and services, including BRT.

3 With the addition of a passing lane at BRT stations and express services, the capacity can go up to 45,000 pphpd.

4 For example, Handy, Susan, and Marlon Boarnet (2014), "Impact of Highway Capacity and Induced Travel on Passenger Vehicle Use and Greenhouse Gas Emissions: Policy Brief," California Air Resources Board, <http://www.arb.ca.gov/cc/sb375/policies/hwycapacity/highway_capacity_brief.pdf>.

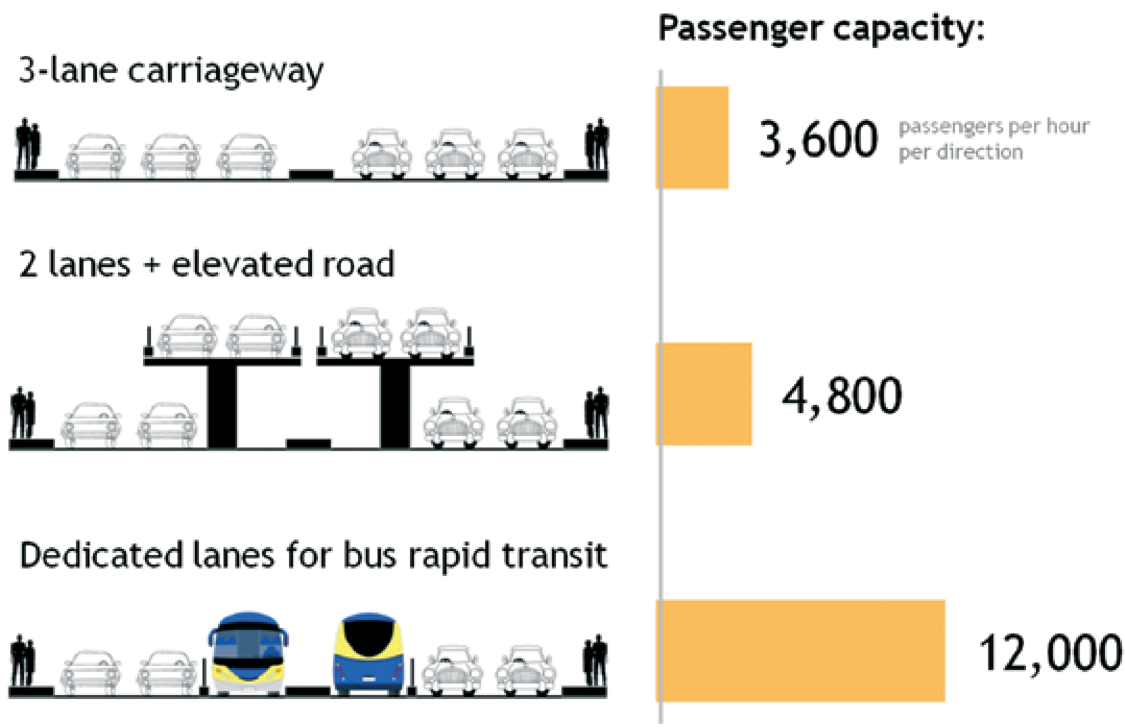


Fig. 5: Expanding road space for personal vehicles results in modest capacity improvements. Allocating dedicated road space for BRT is a more effective way to increase passenger throughput.

On streets with moderate to high demand for public transport (i.e., over 2,000 pphpd), cities should start to plan for BRT integrated with other mass rapid transit services across the city. Further, allocation for BRT corridors must be made on any new arterial streets being planned and implemented. Ideally, dedicated lanes for BRT should be created before traffic congestion sets in. However, even in situations where a public transport corridor is congested with traffic, it is equitable to dedicate lanes for BRT to cater to existing as well as future demand for mass rapid transit.

2.4 BRT and Grade-Separated Rail

A key element of transport planning is the calibration of transport services to the travel patterns and demand level along the corridor in question. A service that is undersized relative to expected demand may result in overcrowding and delays. On the other hand, a system with too much capacity represents an inefficient allocation of resources that could have been used to improve other transport services or meet other basic needs in the city. Therefore, sound transport planning must seek to provide the required capacity on each of a city's transport corridors in a cost-effective way.

High-capacity rail-based modes, such as metro rail systems, can provide high quality service on high demand corridors. However, demand on major corridors in many Indian cities falls in the range of 2,000 to 10,000 pphpd well below the level needed to justify the large capital investment required for a metro rail system (i.e., at least 20,000 pphpd), and well within the range that can be handled by a BRT system with a single lane per direction. The existing arterial streets in many Tier 1 Indian cities, already have more than 100 buses per hour or 6,000 pphpd that make them a strong case for BRT[5].

Large cities (Population > 5 million), a balanced public transport network might include metro rail services on some of the city's highest demand corridors, while the remaining corridors in the city can be served by BRT[6]. In medium-sized cities (population of 1-5 million), BRT typically can provide sufficient capacity to serve the city's *entire* mass rapid transit network. Cities smaller than 1 million typically do not need a rapid transit system and bus and Para transit services are sufficient to serve the demand. However, cities whose population is expected to touch 1 million within the next 5 years should start planning for a BRT system. BRT is also a very cost effective option for the cities having existing population upto 2 million and it should be one of the first considerations in MRT system development in any city.[7] It is suitable for cities where an MRT system needs to be developed quickly and incrementally as conditions and funding.[8]

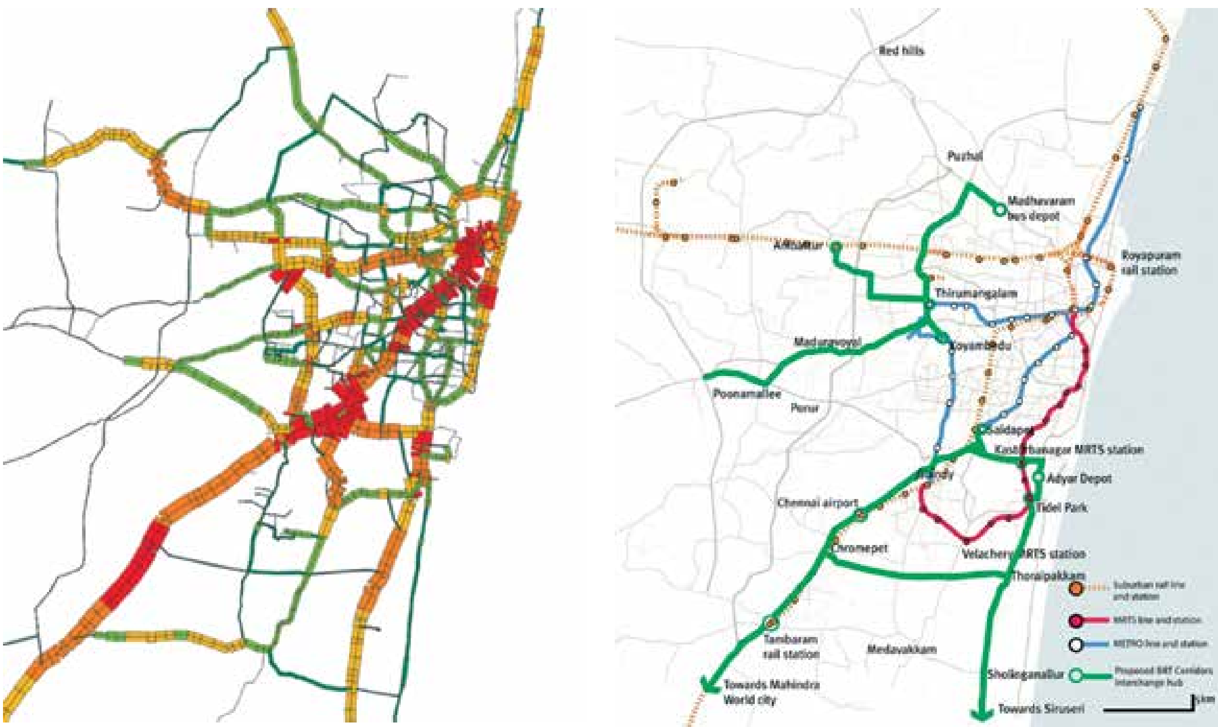


Fig. 6: The choice of rapid transit technologies should correspond to the expected level of demand (left). The city of Chennai is implementing metro rail on three of its highest demand corridors (indicated in blue in the diagram at right). On other corridors, BRT can meet expected passenger demand.

---

5 Volume 1, Table 8.19, URDPFI Guidelines

6 Volume 1, Table 8.19, URDPFI Guidelines

7 Smart City Indicators (Draft), The Bureau of Indian Standards (BIS)

8 Smart City Indicators (Draft), The Bureau of Indian Standards (BIS)

Street level LRT can provide high quality service on corridors with moderate demand, provided that it incorporates the same key features that characterise BRT systems (i.e., dedicated lanes, level boarding, off-board fare collection). LRT lacks the flexibility of BRT and its capacity is limited to around 15,000 pphpd. However, the capacity of an LRT system (with a single track per direction) is higher than that of a single lane per direction BRT system (which peaks at around 12000 pphpd). BRT systems with express services can serve higher demand but require an additional passing lane at the stations to enable overtaking.

Higher capacities can be achieved if LRTs are grade separated, but the cost of LRTs with frequent grade separated elements begins to approach that of metro systems. In sum, high cost of implementing LRT paired with capacities that are equivalent to those of BRT systems typically mitigates against their implementation in cities with limited capital budgets.

3. PLANNING FOR BRT

3.1 Network Selection

An initial step in the BRT planning process is to identify the network of corridors where BRT can and should be implemented. Network selection is a function of multiple considerations, including:

1. Existing and future passenger demand patterns.
2. Presence of severe congestion.
3. The need to offer equitable access to the system to people across all socio-economic groups.
4. Potential to minimise passenger transfers.
5. Potential to minimise land acquisition.
6. Right of Way (ROW) availability.

Passenger demand is a key factor for corridor selection. A BRT system should be located where it will benefit a large number of people relative to the expected investment. While cities are often averse to develop BRT corridors in congested parts of the city where traffic volumes near the capacity of the carriageway, it is precisely these locations that have significant number of passengers on public transport (a combination of buses and informal public transport vehicles such as shared autos and mini buses), and could benefit most by the creation of a BRT.

As has been observed in many cities across the world, creation of a BRT has benefited not just public transport passengers but also people travelling by other modes due to the streamlining of vehicular traffic. However, the primary goal of creating a BRT is to maximise the ability of a corridor to transport people rather than vehicles. This goal has also been noted in the National Urban Transport Policy of the Government of India.

BRT should not be seen as a solution for solving traffic congestion. Even in cases where a BRT is created on less congested corridors, personal motor vehicle traffic growth results in congestion on the mixed-traffic lanes, abutting BRT lanes, within a few years. Instead, it should be viewed as an effective option for those who wish to travel rapidly, safely, and comfortably, even when there is congestion on mixed-traffic lanes of the carriageway.

The only known solutions for controlling traffic congestion are measures that control the demand for the use of personal motor vehicles through physical restrictions or appropriate user charges, such as market-based parking fee and congestion pricing, along with appropriate enforcement measures.

Demand is generally assessed through three basic types of surveys:

- **Frequency-Occupancy (FO) survey:** An FO survey records how frequently each bus or taxi route runs and the approximate occupancy of each vehicle.
- **Boarding-Alighting (BA) survey:** The BA survey is an on-board count of how many passengers get on and off of the vehicle at each stop along the route.
- **Transfer surveys:** A transfer survey is helpful in order to get a better sense of full passenger trips, including trips that involve more than one segment linked by a transfer from one route to another.

A city may opt to gather more data using other types of surveys, depending on system complexity, the project timeline, and availability of funds. Data from travel demand surveys can be processed using a basic spreadsheet model or travel demand modelling tools such as **CUBE, Transcad or Emme**. Key model outputs include the passenger load on different parts of the corridor and the expected boardings and alightings at each station. These demand data are used to determine the alignment and frequency of BRT services. Eventually, they also inform the sizing of stations, terminals, and other physical infrastructure elements. A four-step model is useful to estimate mode shift. However it is equally valid to use rule of thumb to make decisions on network selection.

A BRT corridor should be long enough to provide a meaningful impact on travel times and passenger convenience. If warranted by passenger demand, BRT corridors must continue all the way into congested parts of the city. There is limited utility in building BRT infrastructure in uncongested outer roads while sending buses into mixed traffic as soon as they reach congested areas.

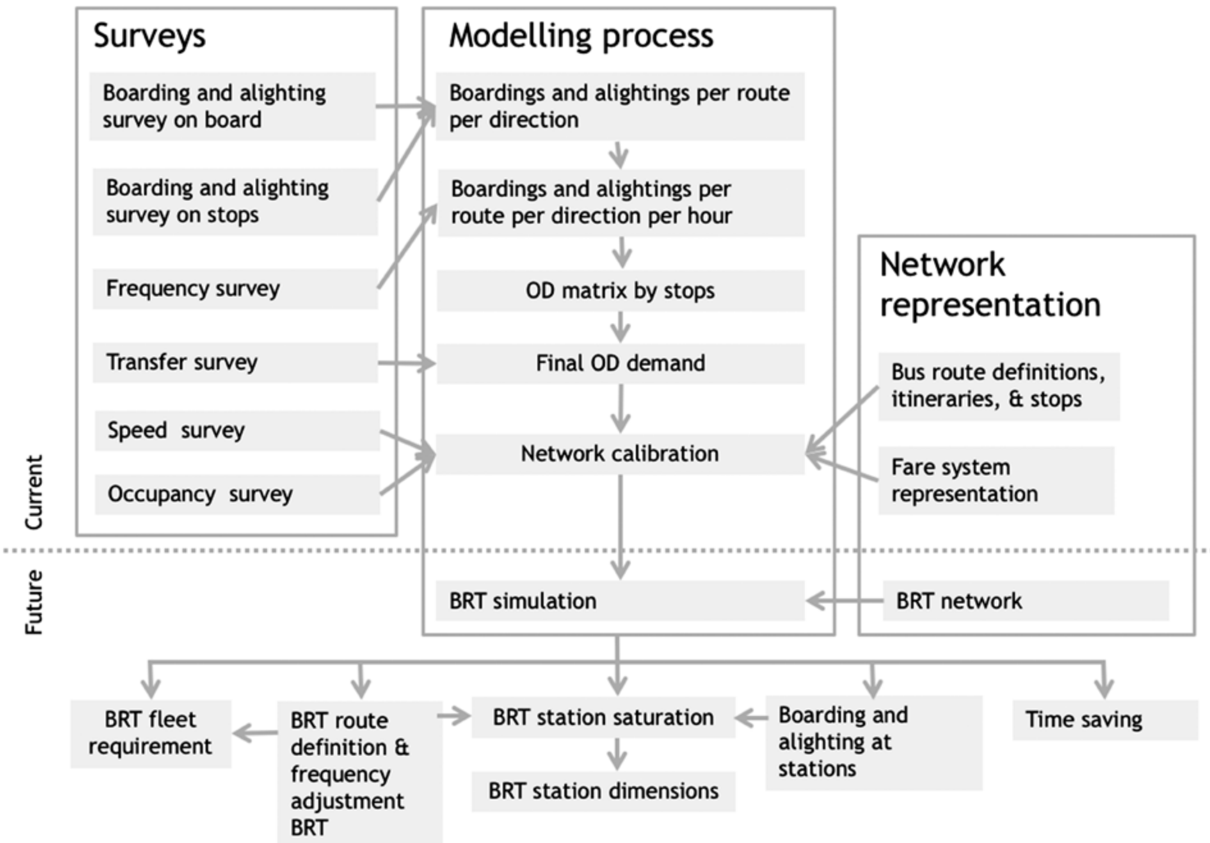


Fig. 7: Demand analysis for a BRT project uses data on passenger trip patterns to develop a service plan. Service plan parameters, such as expected bus frequencies and passenger volumes at each station, inform the design of infrastructure elements, including station sizes.

Photo 5: BRT infrastructure that extends into congested city areas, such as Ahmedabad's walled city (left), helps provide fast, reliable service where passenger demand is highest. Road width need not pose a constraint to the implementation of BRT, as demonstrated by Mexico City (right) and other cities around the world that have built BRT-only corridors in dense city centre environments.

New streets that are developed in the periphery of the city may be designed to be BRT-ready, with space reserved in the centre for a future BRT, especially in the case of streets with a right of way of more than 36 m. This is most effective when such reservations are made in the statutory development plan of the city/region. BRT infrastructure can be created once the demand is high enough to justify dedicated infrastructure.

3.2 BRT Configuration and System Capacity

System capacity refers to the maximum number of people or vehicles that can be moved in a single direction on a BRT corridor. It is important to match the system design to the required capacity, as a design with inadequate capacity can lead to delays, overcrowding, and a poor image for the system.

Among the factors that determine the capacity of a BRT system, the configuration of the lanes and stations is the key. A BRT system with one lane per direction in station areas can handle about 70 regular buses an hour, or around 5,000 pphpd. This configuration is appropriate for the corridor demand in many Tier 2 Indian cities. Above these volumes, bus congestion caused by bus docking at stations results in delays and slower commercial speeds. The capacity of a system with one lane per direction can be increased to around 9,000 pphpd by adding articulated buses or 12,000 pphpd by using bi-articulated buses (see section 4.3, Calculating corridor capacity: basic approach).

In situations with higher passenger demand, passing lanes at stations can increase the capacity of a BRT system. The Transmilenio BRT system in Bogotá (Colombia) can carry up to 45,000 pphpd through the use of articulated and bi-articulated buses, passing lanes at stations, and up to 60 per cent of services operating as express routes that stop only at limited locations. Another system with passing lanes, the Guangzhou BRT system in China, carries 27,000 pphpd.

For passing lanes to function effectively, stations must be long enough to accommodate separate stopping bays, also called sub-stops, that can function independent of one another (see section 4.4). Multiple sub-stops increase the number of buses that can dock at a station without causing congestion and permit different types of services to operate from the same station.

In cases where adequate space for long stations is not available, another possibility is to create stations with docking positions on both sides of the station for a single direction. The additional docking bays allow the system to handle higher bus frequencies without experiencing slow-downs due to congestion at stations. (BRT systems in Lanzhou and Yichang with dual-side docking are able to handle frequencies of 80-100 buses per hour with competitive commercial speeds of 20 km/h or more.)

Some systems with a single lane per direction increase capacity by operating buses in convoys of two or more vehicles operating in a closely bunched pack. In some cases, convoys are able to transport up to 20,000 pphpd in a single lane. However, at volumes above 13,000 pphpd, convoys experience a major deterioration in commercial speeds. If space is available, it is preferable to increase capacity through the use of passing lanes and stations with multiple sub-stops.

With a variety of configurations to handle varying levels of passenger demand, BRT capacities are competitive with rail-based modes. For example, LRT systems typically can accommodate up to 15,000 pphpd with a single track per direction, a level easily achievable with BRT. Monorails are lower capacity systems, handling around 8,000 pphpd on the busiest known systems. BRT with passing lanes, which can carry up to 45,000 pphpd, is comparable with all but the world's highest capacity metro systems.

Photo 6: A single-lane BRT system like that in Mexico city (left) can handle volumes from 5,000 to 12,000 pphpd, depending on the type of vehicle used. With passing lanes at stations, a BRT system can carry up to 45,000 pphpd, the capacity of Bogotá's Transmilenio. iBus, Indore (right) has passing lanes at stations to help cater to future demand. (Photos courtesy ITDP and WRI India Sustainable Cities.)

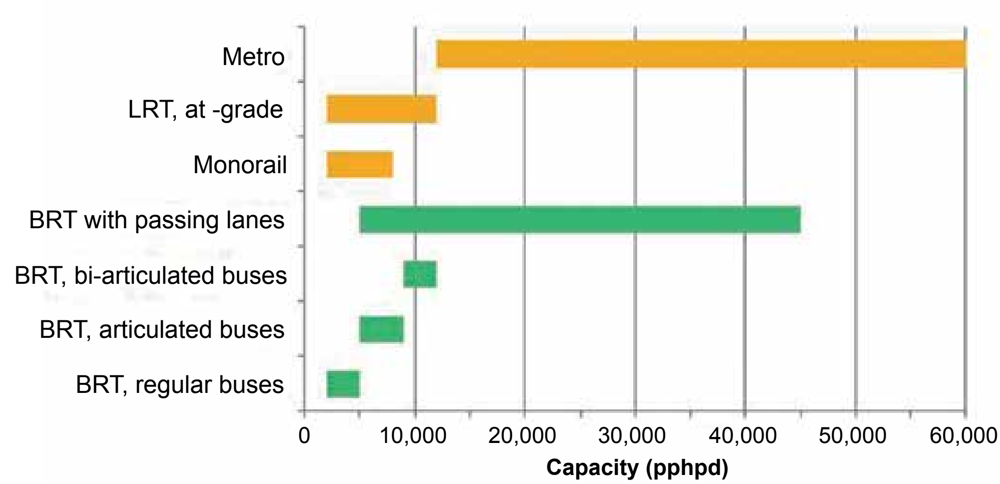


Fig. 8: Capacity of mass rapid transit systems. A simple BRT system with one BRT lane per direction and regular 12 m buses can carry up to 5,000 passengers per hour per direction (pphpd). The capacity increases to 9,000 pphpd with articulated buses and to 12,000 pphpd with bi-articulated buses. The addition of a passing lane brings a dramatic increase in capacity of up to 45,000 pphpd far above the capacity of LRT and monorails and competitive with high capacity metro systems.

4. SYSTEM DESIGN

4.1 Dedicated Bus Lane Alignment

A common misconception is that kerbside alignment of bus lanes reduces the crossing distance for bus passengers. In fact, the overall crossing distance for a round trip is the same whether bus stops are located on the outer edges or the centre of a road. If bus stops are located on the kerb, a passenger can board from the same side for travel in one direction but has to cross the entire road to travel in the other direction. If stops are located in the median, the passenger has to cross half of the street each time. The total crossing distance remains the same.

Photo 7: Median busway alignment avoids conflicts with other traffic, especially from turning movements from mix-traffic lanes: Ecovia, Quito, Ecuador (left) and Rainbow, Pune (right).

4.2 Station Alignment

Common BRT station typologies include the following:

- A single centrally located station serving both directions of service.
- Side stations on the outer edges of a median busway, each serving a single direction of service.
- A pair of two-sided stations, each serving the same direction of travel.

A single central station serving both directions is the configuration employed in most high performance BRTs. This alignment has several advantages:

- **Optimal use of street space:** Central stations require a single entry area and single set of turnstiles; whereas two bilateral stations each require their own entries, thereby increasing the total length of the stations.
- **Easier customer transfers between routes:** Central stations make it easier for customers to transfer from one bus route to another without having to exit the station and cross a street, irrespective of the direction of the two routes.
- **Easier docking:** Bus drivers have an easier time docking stations that are located on the driver's side of the bus.

- **Lower construction and maintenance costs:** Central stations are smaller and are up to 40 per cent less expensive to build and operate than two bus stations on either side of the central bus lanes.

Photo 8: Median stations, such as in Pimpri Chinchwad are less expensive and have a more compact footprint than side stations.

Side stations on the outer edge of the busway are sometimes employed to permit the use of an existing fleet of buses with kerbside doors. However, in such cases, system designers and operators should ensure that only high-quality, low-entry buses are permitted in the BRT corridor. A common pitfall is to open the corridor to multiple types of vehicles with different internal floor heights and mismatched door locations. Doing so renders the system inaccessible to many users, makes boarding slower and less convenient, and generally detracts from system image. Moreover, the cost savings from the use of an existing bus fleet are relatively small in comparison to the overall capital cost of a BRT system. Therefore, it is advisable that a new fleet of compatible, high-quality buses are procured along with the creation of suitable BRT infrastructure. Further, these buses must be maintained well and replaced at the end of their rated life (typically 7-10 years). Well-maintained buses break down less and tend to last longer, resulting in lower cost of operations.

A recent innovation in BRT design is to develop two station buildings, each with boarding areas on both sides serving a single direction. Found in systems in Lanzhou and Yichang (China), such an arrangement increases the number of vehicles that can dock at the station while maintaining a reasonable level of saturation. Both of these systems utilise buses with low-entry doors on both sides.

Potentially, dual-side stations could also introduce multiple dock heights. High-entry buses with median side doors would dock on the left side of the station, while low-entry buses with kerb side doors would dock on the right. An internal ramp would connect the two boarding areas. The high-entry vehicles could be articulated or bi-articulated buses that provide trunk only services while the low-entry vehicles could provide direct services outside the corridor. High level of detailing and utmost design and safety precautions are essential while adopting such a composition.

Photo 9: BRT stations with dual-side docking for buses traveling in a single direction in Lanzhou (left) and Yichang (right).

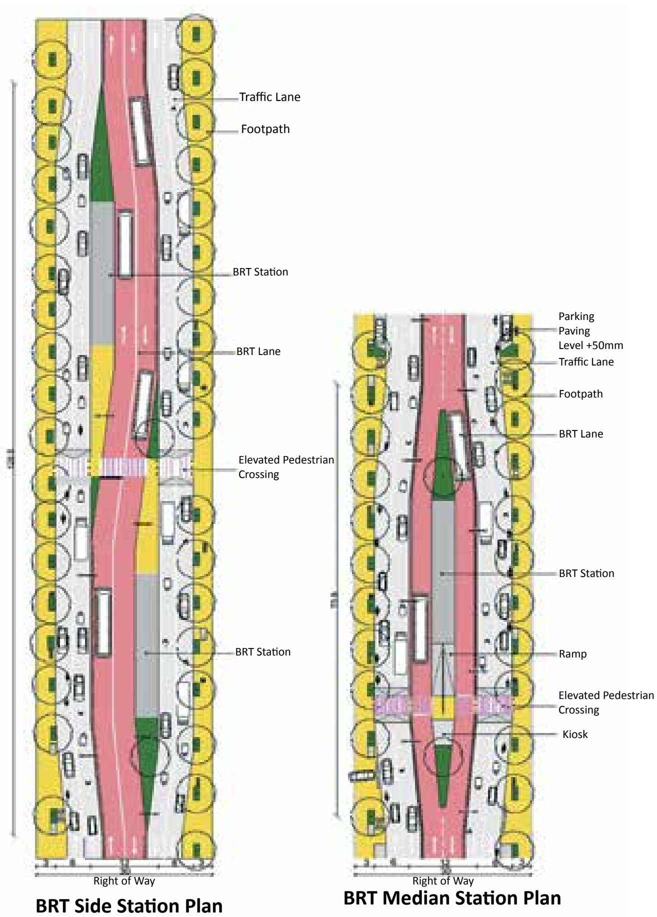


Fig. 9: Median stations (right) require less road space than side-aligned stations (left).

4.3 Calculating Corridor Capacity: Basic Approach

The capacity of a BRT corridor depends on the load factor, vehicle size, the service frequency, and the number of stopping bays at each station. The equation below shows the basic relationship between these factors and the capacity of a BRT system:

$$C_{corridor} = C_{vehicle} * L * F * B$$

Where:

- $C_{Corridor}$ is the number of people the corridor can transport, expressed in passengers per hour per direction (pphpd).
- $C_{vehicle}$ is the passenger capacity of the vehicle.
- *L*, load factor, is the average occupancy of the vehicles, expressed as a per cent.
- *F*, service frequency, is the number of vehicles per hour per stopping bay.
- *B* is the number of independent stopping bays in each station.

Table-2 gives the corridor capacities estimated by the basic capacity formula for a range of frequencies and station sizes. The capacity of a single sub-stop is typically limited to 50-60 buses per hour. This capacity can dramatically reduce when dwell times are longer due to a large number of passengers boarding and/or alighting at certain stops, but, more frequently, due to poor bus docking and restrictions in access to the bus, in the form of narrow doors and/or steps inside the bus, resulting in slower boarding and alighting time per passenger.

As can be seen, the provision of passing lanes and multiple stopping bays leads to a dramatic increase in system capacity. It should be noted that the number of stopping bays also affects the type of busway infrastructure. If the number of stopping bays increases to four or more, then it is likely that two lanes per direction will be required along the entire length of the busway not just at stations.

Table-2: BRT Corridor Capacity Scenarios

Vehicle type	Passenger capacity of vehicle	Vehicle frequency per hour per sub-stop	Sub-stops per station	Approximate peak capacity (pphpd)
Standard	70	70	1	4,900
Articulated	150	60	1	9,000
Bi-articulated	210	60	1	12,000
Articulated	150	50	2[9]	15,000
Articulated	150	50	4	30,000

9 More than one sub-stop per station requires an additional passing lane at the station.

4.4 Station Saturation

The "saturation" of a station refers to the degree to which passenger and bus volumes have reached the station's design capacity. Station saturation is a significant parameter in BRT planning as it indicates the maximum number of commuters that a particular BRT configuration can handle while providing an acceptable level of service.

In literal terms, saturation refers to the percentage of time that a vehicle-stopping bay at a BRT station is occupied. Based on empirical evidence, BRT systems perform best when the saturation level is below 40 per cent at each station. Above this level, BRT systems run the risk of congestion and system breakdown. Therefore, it is desirable to keep saturation levels as low as possible. It should be noted that overcrowding in a station does not necessarily indicate a high level of saturation. Crowding in a station can result from inadequate bus frequency, even if the saturation level is low.

Photo 10: In Sao Paulo, high saturation levels at BRT stations can lead to bus queuing (left). In Jakarta, passengers experience delays due to high saturation levels at major terminals (right).

In systems with moderate demand, stations should be constructed with at least two docking bays per direction. The additional docking bay allows two buses to dock at the station simultaneously. Constructing multiple sub-stops with passing lanes can reduce station saturation further. Sub-stops are independent docking units that allow buses to pass one sub-stop and dock at another. Passing lanes are required at stations to allow buses to pass other vehicles that are stopped for boarding and alighting, but the corridor can return to a single lane per direction between stations.

Each sub-stop is separated from others by minimum of 32 m to allow buses to manoeuvre into and out of each stop regardless of whether the other sub-stops are occupied. Each sub-stop can handle around 50 buses per hour, leading to a dramatic increase in system capacity. Further, express services that stop only at a limited number of stops increase capacity further. Systems have two to three sub-stops per station but some systems have as many as four sub-stops per station. Beyond this, it is better to create a new station with its own sub-stops.

Photo 11: Multiple sub stops increases the capacity inside the station: Transmilenio, Bogotá (left) and Guangzhou BRT (right).

The number of sub-stops required at a station is determined using data on the number of passengers boarding and alighting at the station and the frequency of buses. The following formula indicates the saturation level at a station:

$$X = T_{Dwell} * F + P_{Board} * T_{Board} + P_{Alight} * T_{Alight}$$

Where:

- X is the saturation level
- F, service frequency, is the number of vehicles per hour
- T_{Dwell} is the dwell time in seconds
- T_{Board} is the average boarding time per passenger in seconds
- T_{Alight} is the average alighting time per passenger in seconds
- P_{Board} is the number of boarding passengers
- P_{Alight} is the number of alighting passengers

The readers may refer to additional reference material for detailed calculation technique.[10]

4.5 Calculating Corridor Capacity

4.5.1 *First advanced approach*

While the basic capacity formula described in the section above provides a broad idea of the capacity that is achievable on a BRT corridor, a more detailed analysis of theoretical system capacity should take into account the quantity of passenger movements at each station:

$$C_{corridor} = \frac{3600 \cdot X \cdot B}{\frac{T_{Dwell}(1 - E)}{C_{vehicle}} + R \cdot T_{passenger}}$$

---

[10] TCQSM. (2013). Kittelson Associates, Inc. TCRP Report 165 - Transit Capacity and Quality of Service Manual. Prepared for Transit Cooperative Research Program, Transportation Research Board, National Research Council, Washington DC.

Where:

- $C_{corridor}$ is the number of people the corridor can transport, in passengers per hour per direction (pphpd)
- $C_{vehicle}$ is the passenger capacity of the vehicle
- X is the saturation level
- B is the number of independent stopping bays in each station
- E is the fraction of vehicles providing limited stop or express service
- R is the renovation rate, the total boardings along a given route divided by the maximum load on the critical link
- T_{Dwell} is the dwell time of the vehicle
- $T_{passenger}$ is the average boarding and alighting time per passenger in seconds

4.5.2 *Second advanced approach*

The second advanced approach is based on the Levinson's approach as mentioned in the latest transit capacity and quality service manual. TCQSM (2013) reported a model to estimate the bus stop capacity as shown below:

$$B_s = Nel \frac{3600(g/C)}{t_c + t_d(g/C) + Zc_v t_d}$$

Where B_s is the bus stop capacity, Nel is the number of the effective loading area; t_d is the average dwell time(s). This model with some improvements in the estimation of its components for Indian condition can be used to estimate the capacity of the BRT corridor. For using this model, first the dwell time is estimated as presented in the equation below:

$$Dwell\ Time = P_a t_a + P_b t_b + BLT$$

Where 'P_b' and 'P_a' are the number of passengers boarding and alighting, 't_a' and 't_b' are per person alighting and boarding time, 't_{oc}' is the bus door opening and closing time and BLT is the bus lost time or boarding lost time. Bus Lost Time (BLT) which is a recently introduced component of dwell time is defined as the waiting time for a bus, between when the bus comes to stop in its loading area and when the first passenger boards the bus (Jaiswal et al. 2010). BLT, in other words, is the additional time apart from the passenger service times and bus door opening time, which should be added in the dwell time estimation model. Since BRTS in India majorly has two loading area stops hence, a BLT of 2.3 sec for loading area 1, and 3 sec for loading area 2 can be used (Kathuria et al. 2016). Once the dwell time is estimated then, the mean dwell time (t_d) and the C_v i.e. the coefficient of variation can be estimated from the same.

The second step is to estimate the failure rate. The failure rate is defined as the percentage of buses that arrive at the bus stop to find all available loading areas already occupied. Failure rate data can either be collected manually or by videography survey. The value of Z in the capacity model can be estimated only when the failure rate is known. TCQSM (2013) provides values of Z corresponding to the operational failure rate (see **Table-3**).

Table 3: Value Corresponding to Failure Rate

Z	Failure Rate (%)
2.330	1
1.960	2.5
1.645	5
1.440	7.5
1.280	10
1.040	15
0.840	20
0.675	25

To get the maximum capacity of the system, a failure rate of 25% is recommended. This value is suggested so that a trade-off between failure rate and operational reliability of the system is maintained. A failure rate value higher than this will result in flow exceeding capacity.

Bus clearance time (t_c) is estimated as presented in the equation below.

$$t_c = t_{su} + t_{re}$$

Where t_{su} is the minimum time for the bus to start and cover its own length and the next bus to come and pull in, t_{re} is the re-entry delay. The re-entry delay in the case of BRT system is zero because BRTS has dedicated lane and the bus stops are located online but not offline.

Nel in capacity model i.e. the number of effective loading area is considered because in constrained situations buses in the rear loading area have to wait for exit till the front loading is empty. To counter this effect, effective loading area is considered. TCQSM(2013) suggest 1.75 as Nel value for two loading area online stop. The Nel value for different number of loading areas is given in **Table-4**.

Table 4: Efficiency of Multiple Linear Loading Areas at Bus Stops

Loading Area	Effective Loading Area
1	1.00
2	1.75
3	2.45
4	2.65
5	2.75

After putting all the parameters in the above model, the stop capacity is calculated. The minimum stop capacity is the corridor capacity.

5. STATION DESIGN

Stations play a major role in shaping a passenger's overall experience of using a BRT system. Stations need to have sufficient capacity to handle anticipated ridership, and should offer a safe, comfortable space that eases the wait. Beyond functionality, stations are important in defining the image of a BRT system. A prominent, attractive station has the potential to inspire the communities around it and demonstrate that BRT is a lasting investment in the urban environment.

Photo 12: Examples of BRT stations: Rainbow, PimpriChinchwad (left), and iBus, Indore (right). (Photos courtesy: ITDP and WRI India Sustainable Cities)

5.1 Bus-Station Interface

Buses and stations must be designed together to ensure that a BRT system is accessible to all. To reduce boarding and alighting time, the station platform level should be at the same level as the bus floor. Internal steps render a system completely unusable by persons in wheelchairs, and even small steps can cause significant delays for the elderly, disabled, or people with suitcases or strollers. To accommodate such users, BRT systems require, modern buses with floor height that matches the height of the station floor.

The reduction or elimination of the vehicle-to-platform gap is also key to customer safety and comfort. The gap between the station and the bus should not be more than 5 cm. Physical measures such as kassel kerbs or alignment markings can help guide bus drivers closer to the station. In addition, alignment markings can be placed on the bus dashboard and in the bus lane. Ultimately, good bus docking is a function of the level of driver training and system monitoring (**Photo-14** and **Photo-15**).

To further improve safety, many BRT systems make use of sliding doors at stations. Doors give a degree of security to commuters and they protect against weather, reduce accident risks, and prevent fare evaders from entering the BRT system.

Photo 13: Kassel kerbs in Cape Town (left) and alignment markings in Johannesburg (right) help buses dock at BRT stations. (Photos courtesy UN-HABITAT)

Photo 14: Precision docking and alignment with BRT stations, Janmarg, Ahmedabad. (Photos courtesy Precision SAMARTHYAM)

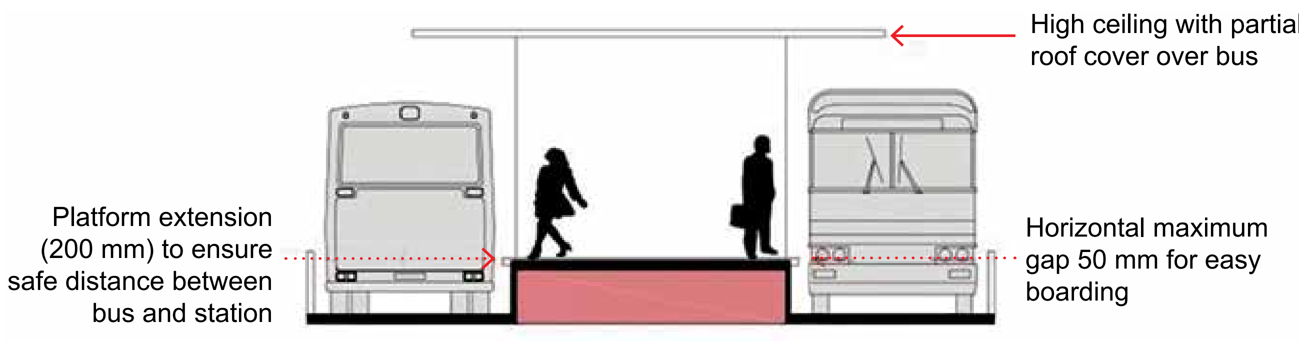


Fig. 10: Elements of the bus-station interface.
(Platform and bus floor at same level)

Photo 15: At-level boarding, demonstrated in Ahmedabad (left) and Lanzhou (right), makes boarding and alighting safe and easy, particularly for the elderly, disabled and people with special needs. It also improves system speeds by minimising the time taken for boarding and alighting.

Photo 16: Sliding doors at stations improve as safety for passengers and prevent fare evasion: Rainbow BRT, Pimpri-Chinchwad(left) and iBus, Indore (right).
(Photos courtesy: WRI India Sustainable Cities)

BRT vehicles should be designed with sufficient number of wide doors to facilitate rapid boarding and alighting at stations. Regular 12 m buses should have at least two doors on the station side, while articulated buses should have four doors. Each door should be at least 1.2 m wide. Where doors are situated together, they should be separated by at least 400 mm. However, it is recommended that there be a greater gap between the two doors of the bus for better internal circulation and lower ingress/egress times.

In case of buses with median doors for trunk corridor operations, doors also should be provided on the left side of the bus to enable the system to operate direct services that extend beyond the dedicated corridor. BRT vehicles need to comply with the urban bus design standards, as developed by the Ministry of Housing and Urban Affairs, Government of India. (see Section 8,Vehicle Specifications).

Photo 17: Wide doors on the station side of buses allow for fast boarding and alighting: 18 m articulated bus in Transmilenio, Bogotá (left) and a 12 m bus in Rainbow, Pune (right).

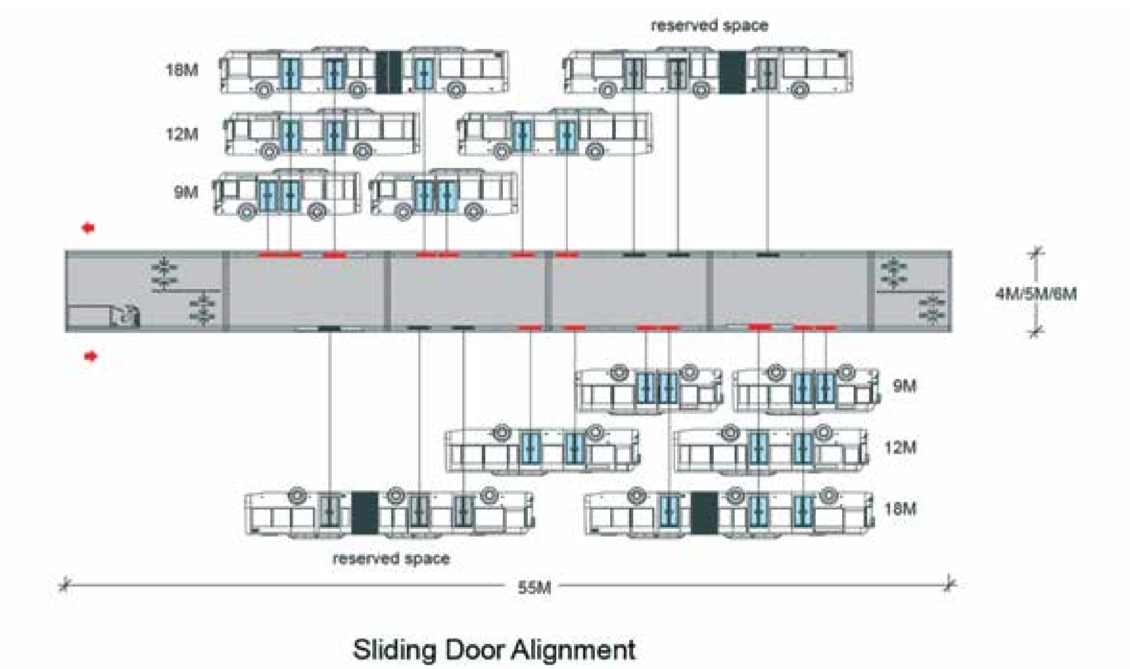


Fig. 11: The alignment of bus and station doors should be designed to accommodate all types of vehicles that are expected to ply on the corridor in current and future phases.

5.2 Station Layout and Size

A BRT station contains three primary areas:

- Ramp(s): Provided on one or both ends of the station, ramps make the station accessible to all users. The ramp should have a slope not exceeding 1:15, making it convenient for the disabled. The ramp should have railing on both sides and should have tactile paver blocks for people with visual impairments.
- Fare collection area: The fare collection area contains system information displays and a place for customers to buy tickets. The ticketing booth should be at least 1.1 m by 1.5 m. Turnstiles or flap-gates should be provided for off-board fare collection.
- Boarding area: The boarding area should provide space for people waiting for buses as well as circulation space for people entering or leaving the station. For small to medium stations, bus-docking positions on either direction should be staggered for easy circulation of people inside the station.

Together, these elements typically add up to a length of 70 m for a moderate-demand BRT system with 12 m buses.

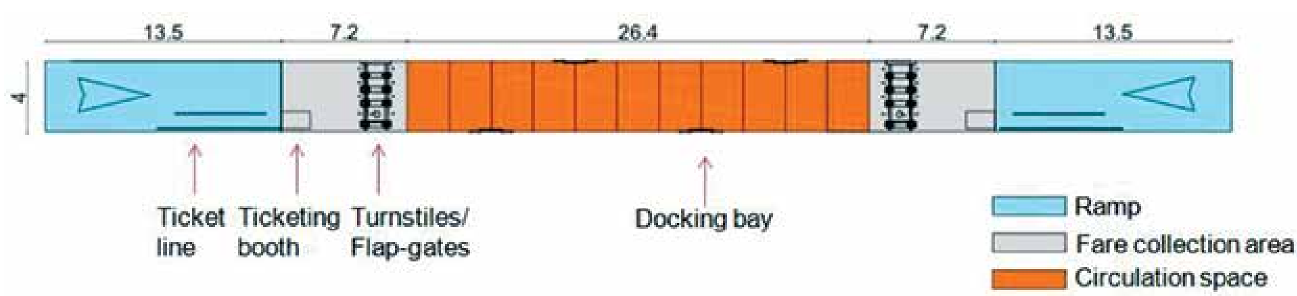


Fig. 12: Typical BRT station configuration incorporating ramp, fare collection area, and circulation space.

The width of station platform depends on width of the structural elements, the waiting area for both directions, and circulating width. Staggering the docking bays for opposite directions reduces the total width required. Length required for waiting passengers at each docking bay should be equal to the length of the bus. Width required for waiting passengers depends on the peak demand at a given station and the frequency of the buses. Circulation width depends on the total number of boarding and alighting passengers during peak hours.

Poor bus operations result in long waiting times and crowded stations. Further, if the space within a station is inadequate for the volume of passengers it is expected to handle, bus boarding and alighting times increase due to crowding, and the efficiency of the system deteriorates.

It is recommended that stations have a width of at least 4 m to provide room for waiting and circulation. The internal clear width should be minimum 3 m in case of a one-way BRT station.

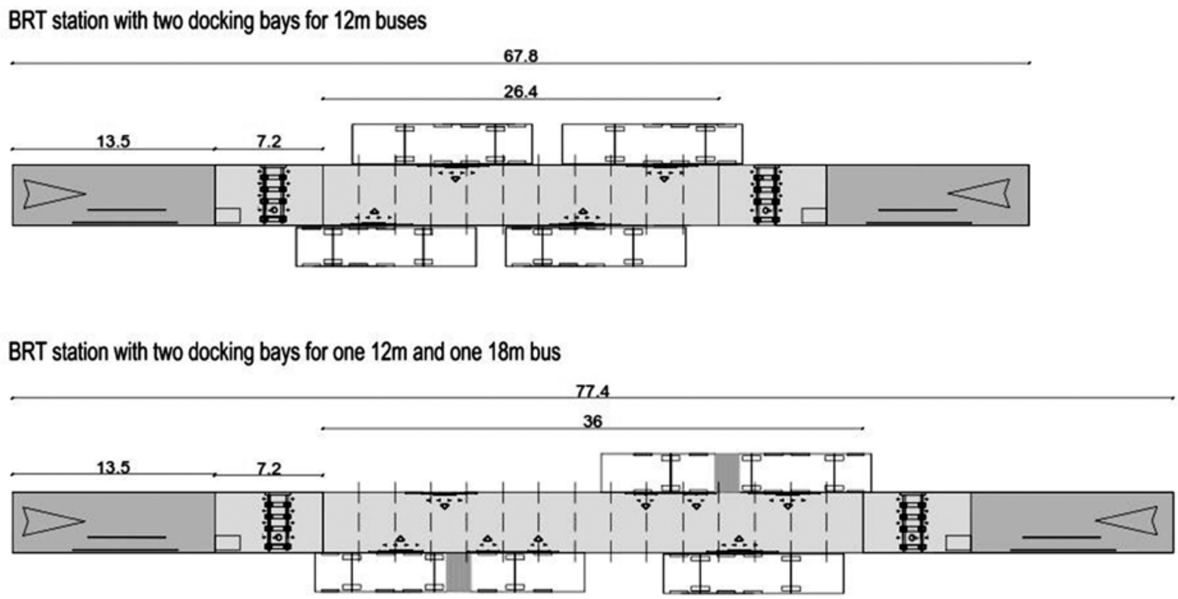


Fig. 13: Station configurations for systems with various levels of demand.

When the demand is high, systems should be designed with passing lanes and independent sub-stops. The distance between the independent sub-stops should be approximately 1.8 times for buses to manoeuvre easily. BRT stations should be designed to allow for the addition of new modules based on future increase in passenger demand. Space in the median may be reserved for future extension of the station.

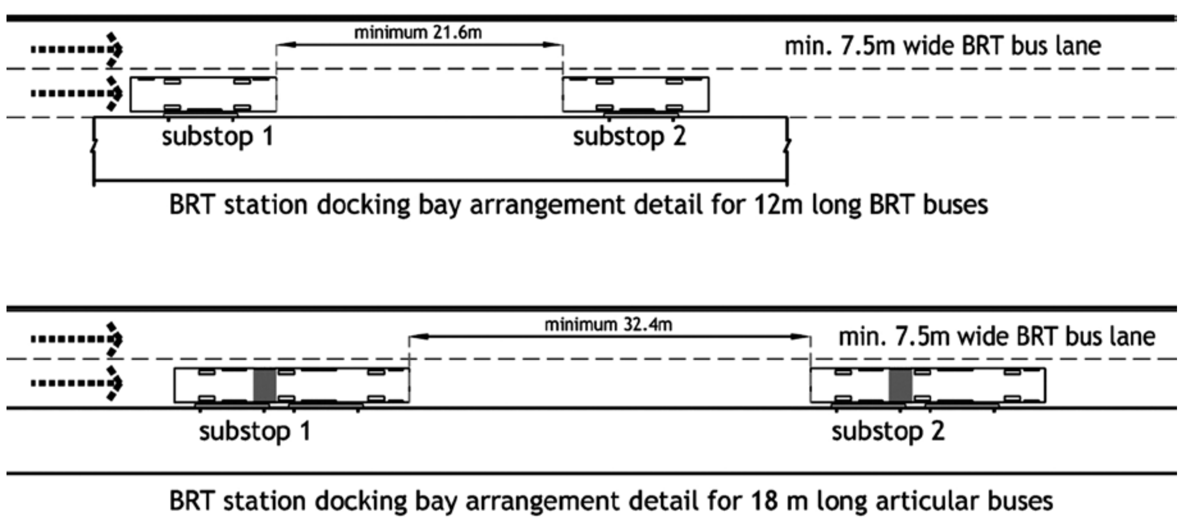


Fig. 14: At stations with passing lanes, the distance between two docking bays on stations should be 1.8 times the length of the bus for easy manoeuvring. For 12 m BRT buses, the distance between two docking bays should be at least 22 m, while for 18 m buses; the distance between two docking bays should be at least 32 m.

5.3 Distance between Stations

Stations should be placed at an average spacing of 500 m in order to ensure that bus stops are accessible to adjoining neighbourhoods. With greater station spacing, the increased time spent walking to the stations more than offsets any gains due to higher bus speeds. Stations that are too close result in lower bus speeds. Accepting that spacing may vary from station to station depending on local conditions, systems should aim for spacing in the range of 300 m to 800 m.

Photo 18: An average spacing of 300 to 800 m between stations is optimal for passengers.

5.4 Architectural Features

The waiting area of a BRT station must provide seating, lighting, and real-time passenger information. The use of open station architecture allows for natural ventilation and lighting (see **Photo-19**). However, the station roof should provide protection from rain and sun. An overhang is preferred to shelter passengers when boarding or alighting. Stations should be built with durable, low-maintenance materials to minimise maintenance costs.

Photo 19: The BRT stations should offer seating, leaning bars, and adequate circulation space to meet expected passenger demand: Rainbow, Pimpri-Chinchwad, India (left) and GZ BRT, Guangzhou, China (right).

Photo 20: Passive solar design provides shading and encourages natural ventilation: Janmarg, Ahmedabad, India (left) and Yichang BRT, China (right).

For night-time operations, adequate lighting (e.g., an illumination level of 150 lux) should be provided to ensure the safety of BRT passengers. Reduced intensity lighting should be provided at station ends to mitigate changes in brightness experienced by the driver while pulling into the station.

Photo 21: Adequate lighting at BRT stations is important to ensure passenger safety and comfort: Mio BRT, Cali (left) and Transmilenio, Bogotá (right).

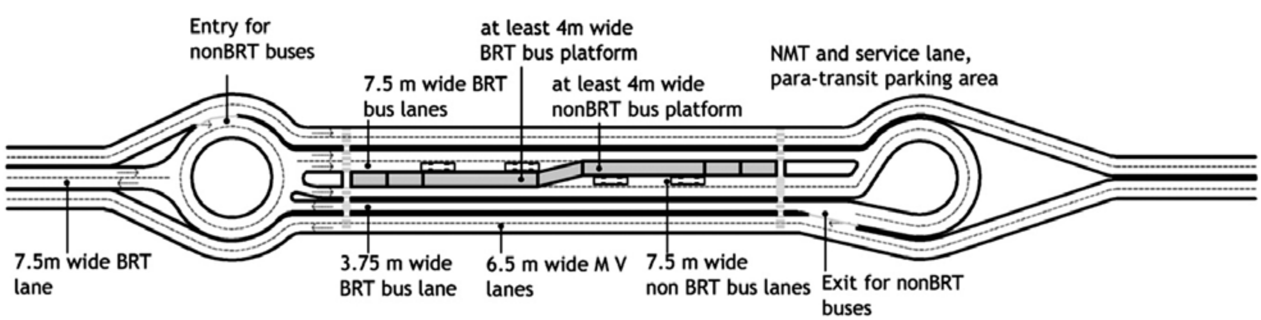
5.5 Terminal Design

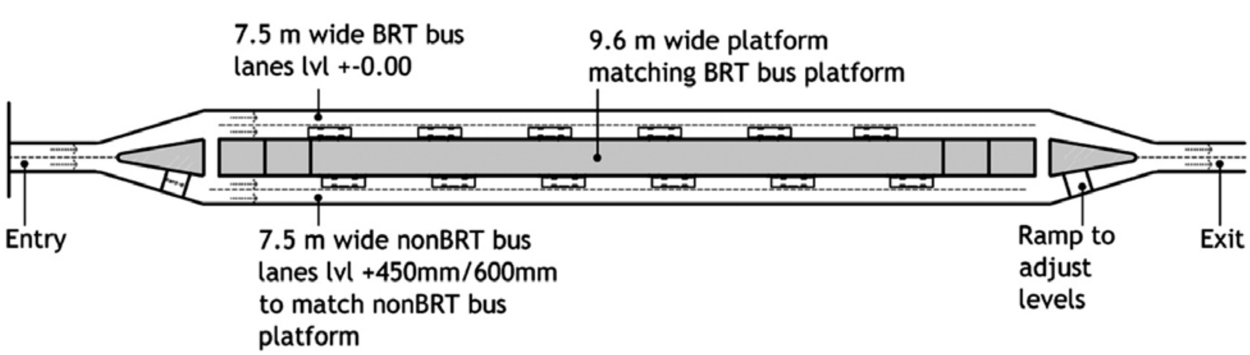
A terminal is a large station that functions as a major interchange between trunk and feeder routes or between the BRT system and para transit or intercity services. Individual bus routes often start or end at terminals. The location of terminals is a function of passenger demand requirements, travel patterns, and the size of the BRT network. Terminal and interchange facilities require space for the buses to turn around and multiple bays for the various routes that pass through the terminal.

Larger terminals should also provide passenger amenities, administrative offices, and space for midday bus parking. Depending upon availability of land, the terminals may either be sited within the corridor ROW or slightly off the corridor. However, the position of a terminal should be close enough to major destinations to facilitate passenger access by foot and on other modes.

Good terminal design should minimise bus circulation and passenger movements. A single platform serving BRT buses on one side and feeder buses on the other is the most convenient design for passengers. It also permits fare free transfers or integrated fare collection, depending on the fare structure of the system. BRT and non-BRT platforms need physical separation in between the two areas if transfers are not free.

Photo 22: BRT terminals designed to facilitate transfers between trunk and feeder services: Transmilenio, Bogotá (left), and Rainbow, Pimpri Chinchwad (right).





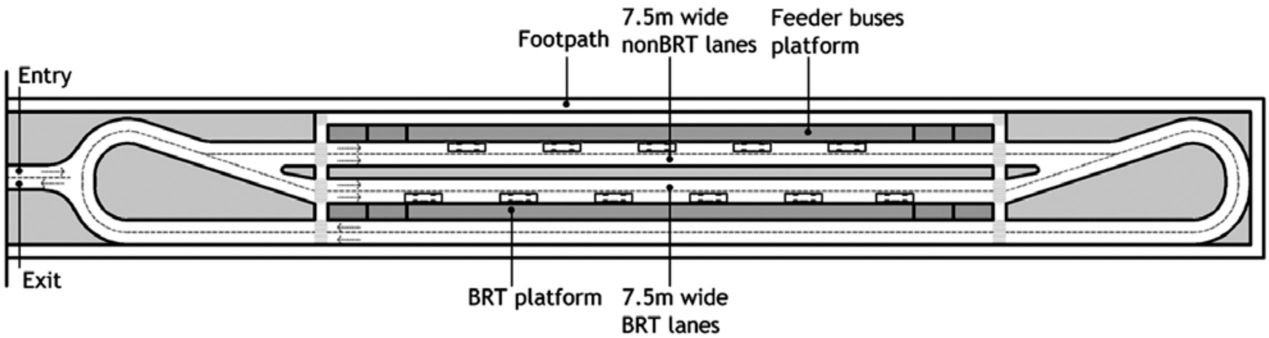


Fig. 15: Possible terminal arrangements: for lower-demand systems, a 118 m long off-set terminal accommodates transfers between BRT services and regular city buses (top); for higher volumes, a longer platform is required (middle); and for high volumes, the trunk and feeder platforms can be split entirely (bottom).

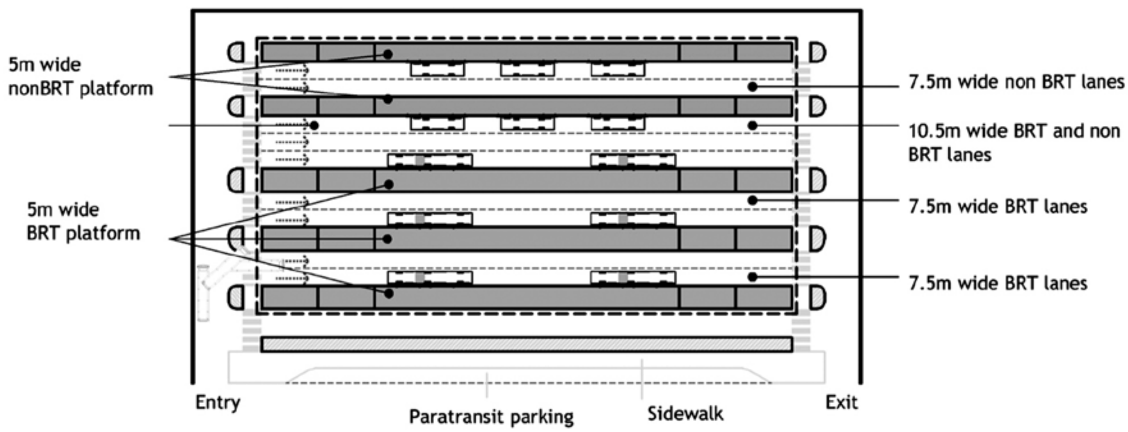


Fig. 16: If bus frequencies and passenger volumes are high; terminals can include multiple platforms under a single roof.

6. CORRIDOR DESIGN

6.1 Street Elements and Design Configurations

BRT corridor design requires careful planning covering cross section designs, busway placement, intersection treatments, and station positions. BRT corridors function best if they are designed to meet the needs of all users, including public transport users, pedestrians, cyclists, and personal motor vehicle users.

Various elements of a BRT corridor and their suggested dimensions are given below:

- BRT lane for one-way movement should have a width of 3.5 m. The width of a passing lane, where required, should be 4 m.
- A divider, minimum 0.5 m wide, should separate BRT lanes from mixed traffic. These should be expanded to at least 1 m at street crossing points by marginally reducing carriageway and BRT lane width.

- Median stations that serve both directions of BRT services should have a minimum inner clear width of 3.5 m. The outer width would be minimum 4 m. Station width may have to be expanded based on passenger demand. If adequate width is not available, then the boarding areas for the two directions may be staggered to reduce the conflict between passengers waiting to board and those alighting and wanting to exit.
- The width of all BRT elements, at station locations without passing lanes, should be 12 m. In case of systems that require a passing lane, the total width of BRT elements at station expands to 16 m. Since passing lanes are not required at non-station locations, the width of BRT elements drops to 8 m in both cases.
- Footpaths are essential for safe pedestrian access to BRT stations. Footpaths with a minimum clear width of 1.8 m should be provided on either side of the carriageway. A tree line next to the footpath with a minimum width of 1 m should be included at all locations.
- Cycle tracks may be provided along the corridor for the safety and convenience of cyclists where adequate right of way is available.
- In case of BRT, since a majority of large vehicles (buses) do not use the carriageway, the carriageway width may be reduced from 7 m to 6.0-6.5 m.
- At non-station locations along the BRT corridor, parallel parking may be provided at the edge of a carriageway or a service lane, depending on the chosen street cross-section.

Table 5A: BRT Corridor Elements: Widths

Street element	Specifications	Minimum width (m)	Maximum width (m)
BRT lane	One-way lane	3.5	4.0
BRT lane	Two-way lane	7.0	7.5
BRT station	Median station	4.0	*
BRT lane	Passing lane at station	4.0	4.5
Buffer between BRT and mixed-traffic lanes		0.5	*
Pedestrian refuge		1.0	*
Carriageway	Mixed traffic lane (per lane for carriageways with two or more lanes per direction)	3.0	3.5
Parking	Parallel parking for cars; perpendicular parking for motor cycles and bicycles	2.0	2.5
Cycle track	One-way	2.0	*
Cycle track	Two-way	3.0	*
Footpath	Clear width	1.8	*
Footpath	Total width including furniture zone and frontage zone	3.3	*
Kerb-side bus stop for BRT direct services and other buses		2.0	*
Tree line	Next to the footpath or in the parking lane	1.0	*

* Width as per requirement

Table 5B: BRT Corridor Elements: Heights (with Respect to Carriageway Level)

Street element	Specifications	Minimum height (mm)	Maximum height (mm)
BRT lane	BRT lane between stations	0	0
BRT lane	BRT lane at station	0	150
BRT Station	Station height	At the same height as the bus floor	
Carriageway	Tabletop crossings	100	150
Footpath		100	150
Cycle track		100	100
Bus stop	Kerb-side bus shelter	150	150

BRT requires wider cross sections at stations. Elsewhere, a multi-utility zone that provides space for on-street parking and bus stops can occupy the extra 4 m of ROW that is available between stations. Walking and cycling provide last-mile connectivity to BRT stations, and space for these modes should not be compromised in station areas. BRT lanes require physical separation to prevent entry by mixed traffic. Physical delineators should be paired with adequate signage and road markings to alert personal motor vehicle users that they may not enter the lanes.

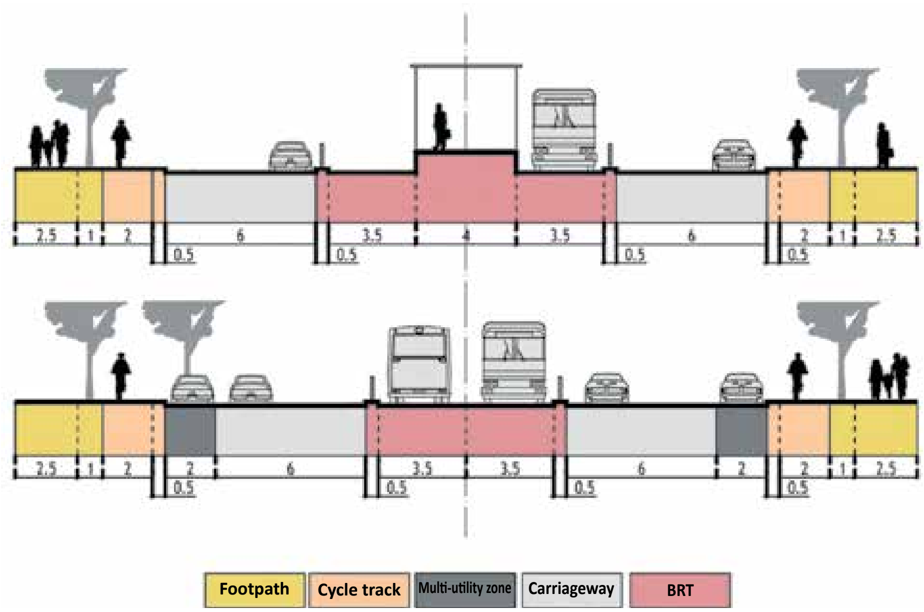


Fig. 17: A typical BRT configuration on a street with 36 m ROW. The upper figure shows the cross section at a BRT station and the lower one shows the cross section at non-station location. (All dimensions in metres)

A BRT corridor with all elements BRT stations and lanes for both directions; 2-lane carriageways, one for each direction; footpaths with tree cover and cycle tracks at both edges can be accommodated on streets with an ROW of 36 m and above. Parking may be provided on such a street at non-station locations. A typical BRT corridor configuration for a 36 m ROW is illustrated in **Fig. 20**.

A minimum of 30 m ROW is required to develop a BRT corridor that serves both directions of travel on BRT as well as motor vehicles (carriageways of 2 lanes per direction). This section has safe walking space an essential element but not cycle tracks or service lanes (**Fig. 18**).

Introducing passing lanes at stations allows the system to accommodate a larger number of passengers. A 36 m wide street can accommodate passing lanes but with the omission of cycle tracks or service lanes. **Fig. 19** shows a configuration on a 42 m ROW that has BRT passing lane. This configuration shows a shared space at the street edge that is primarily meant for pedestrians but can be accessed by motor vehicles at very slow speeds to access properties and parking. An additional dedicated footpath is also present at non-station locations in this cross-section.

Successful design interventions, in Latin American cities such as Quito, Medellin, and Mexico City, have demonstrated that BRT can be implemented even on narrow streets, especially in old city areas and heritage districts. **Fig. 21** gives suggested cross-sections for streets with ROW of 16-24 m. While one or more elements are omitted in these configurations,safe walking space an essential element is ensured in all these sections. For example, on an 18 m ROW, only one-way movement is possible for BRT as well as other vehicular traffic. In case of a 16 m ROW, two-way movement of BRT is accommodated but there is no space for other vehicular traffic in either direction.

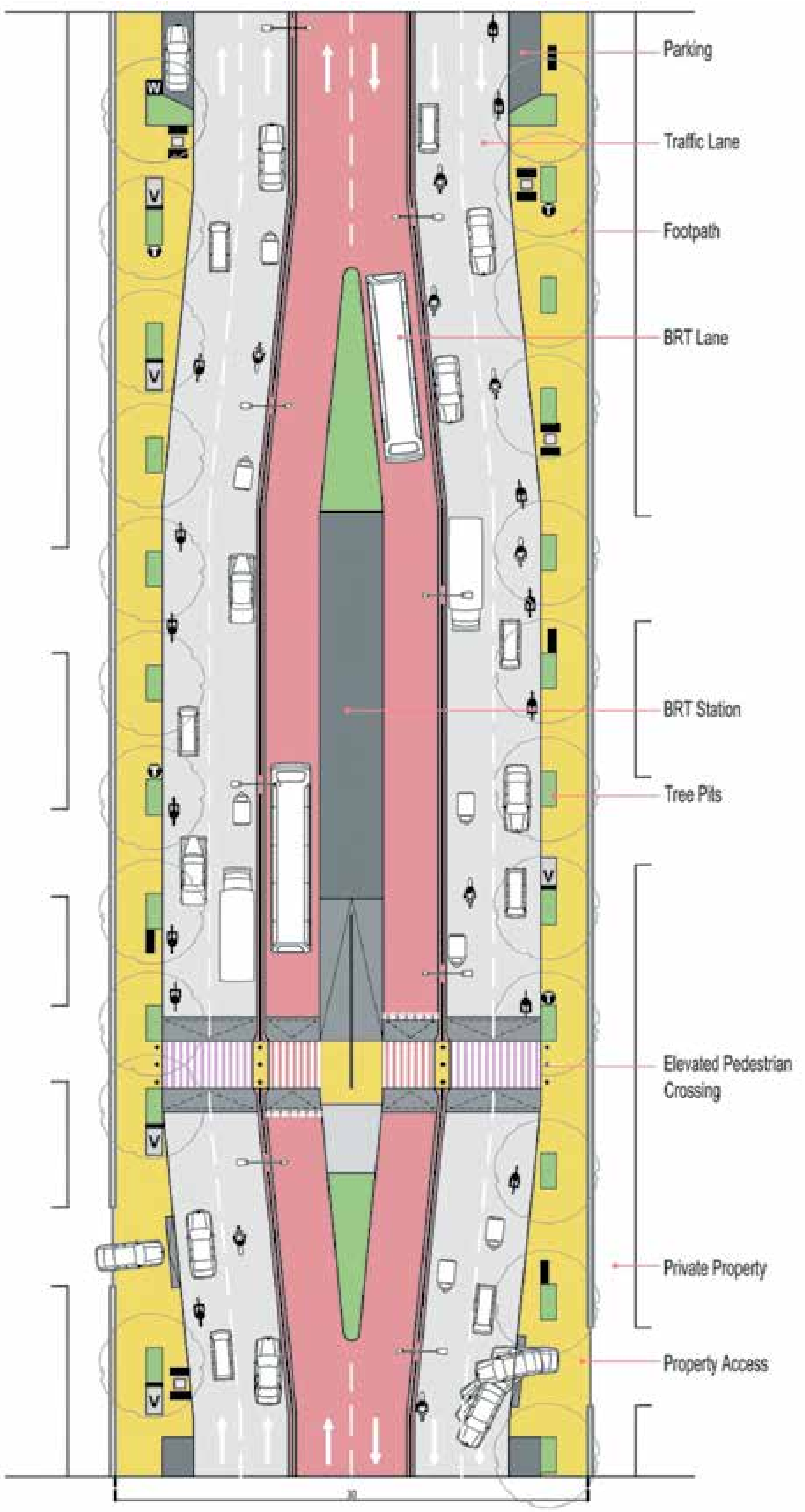


Fig. 18: Plan view of a typical BRT configuration without passing lanes (30 m street)

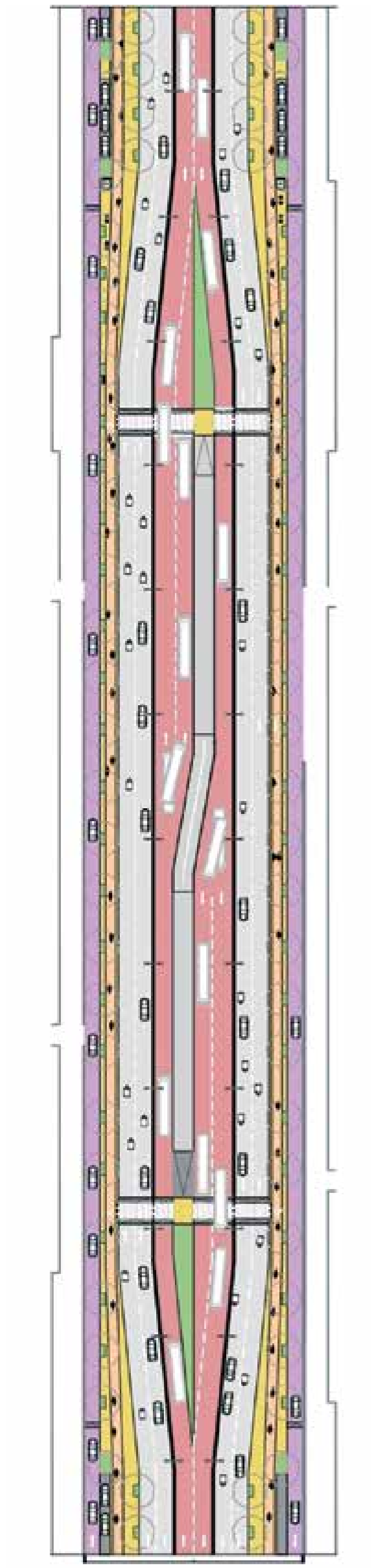


Fig. 19: Plan view of a typical BRT configuration with passing lanes (42 m street)

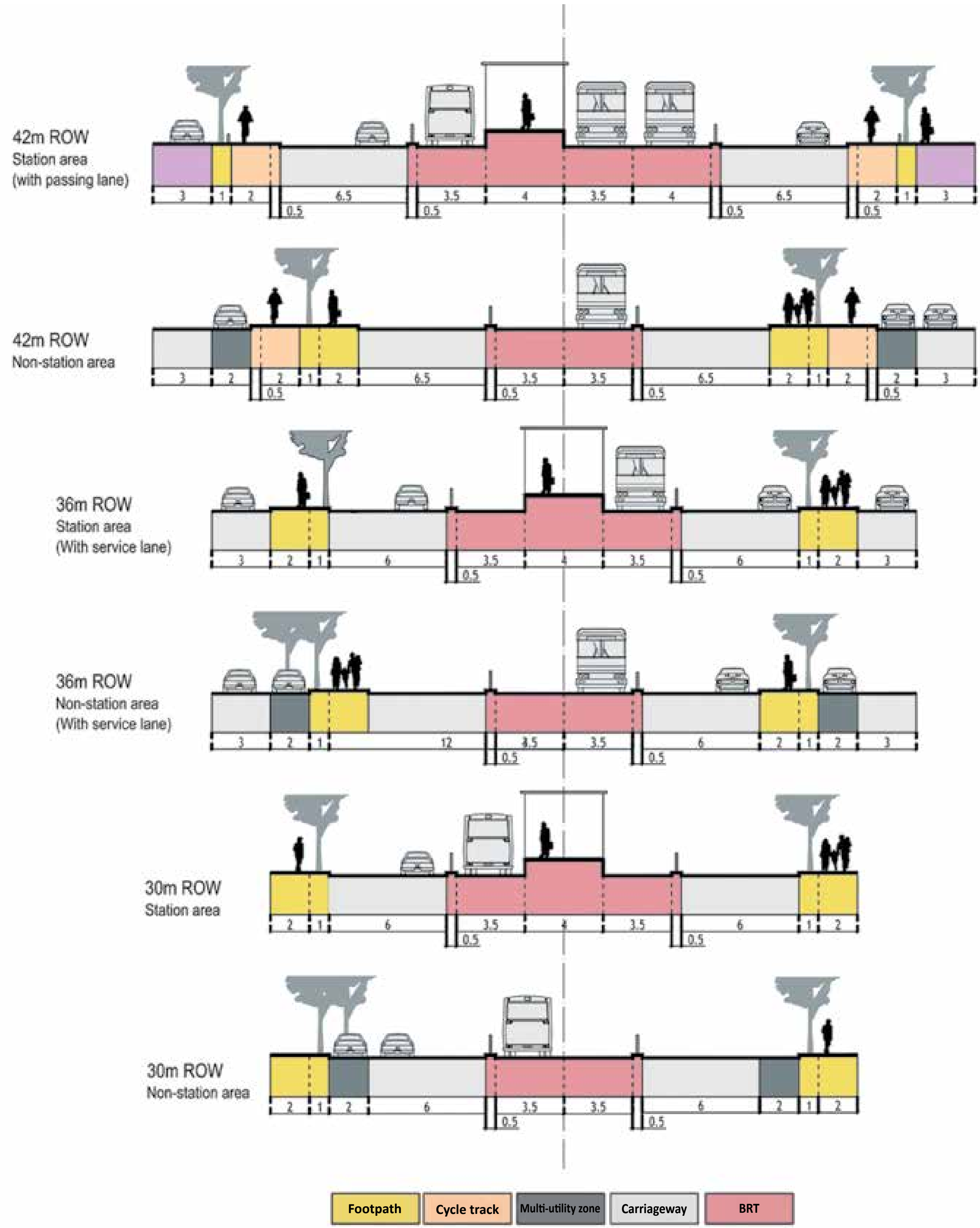


Fig. 20: BRT cross sections for ROWs of 30m and above

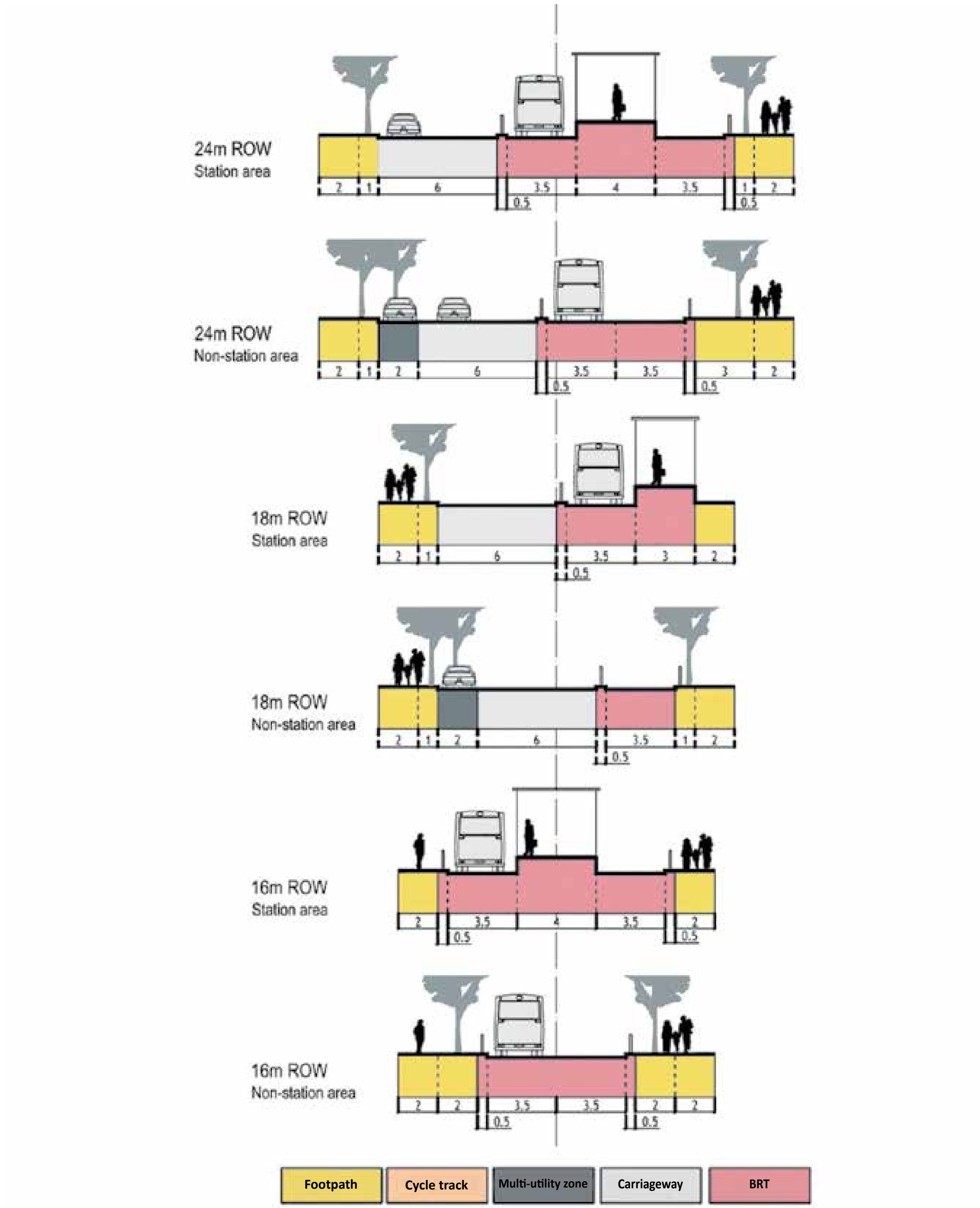


Fig. 21: BRT cross-sections for ROWs of 24 m and under

Table-6A & **Table-6B** provide a matrix of various elements and street widths, along with suggested dimensions for each element. On corridors marked for future development of BRT, a median of 12 m should be reserved for BRT infrastructure. This median reserve provides space for two-way BRT lanes and stations. The exact position of stations can be determined at a later point based on passenger demand and operational requirements and intersection locations.

Table 6A: BRT Corridor ROW Configurations (BRT without Passing Lane)

ROW	36m		30m		24m		18m		16m	
	at station	non-station	at station	non-station	at station	non-station	at station	non-station	at station	non-station
Footpath	2.5	2.5	2	2	2	2	2	2	2	2
Tree/furniture	1	1	1	1	1	1	1	1		2
Cycle track	2	2								
Cycle track buffer	0.5	0.5								
Parking/bus stop		2		2		2		2		
Carriageway	6	6	6	6	6	6	6	6		
BRT divider	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
BRT lane	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5
BRT station	4		4		4		3		4	
BRT lane	3.5	3.5	3.5	3.5	3.5	3.5			3.5	3.5
BRT divider	0.5	0.5	0.5	0.5	0.5	0.5			0.5	0.5
Carriageway	6	6	6	6						
Parking/bus stop		2		2						
Cycle track buffer	0.5	0.5								
Cycle track	2	2								
Tree/furniture	1	1	1	1	1	3		1		2
Footpath	2.5	2.5	2	2	2	2	2	2	2	2

FEATURES/ HIGHLIGHT	Two-way BRT, carriageways and cycle tracks	36m section minus cycle track	one direction carriageway	24m section minus one direction BRT	30m section minus both direction carriageway
BRT	Two-way without overtaking lane	Two-way without overtaking lane	Two-way without overtaking lane	One-way without overtaking lane	Two-way without overtaking lane
Carriageway	Two-way	Two-way	One-way	One-way	No
Cycle track	Yes	No	No	No	No
Footpath	Yes	Yes	Yes	Yes	Yes
Parking	Yes	Yes	Yes	Yes	No
Service lane	No	No	No	No	No

Table 6B: BRT Corridor ROW Configurations (BRT with Passing Lane)

ROW			42m
at station		non-station	
Shared lane/footpath	3	Service lane	3
Tree/furniture	1	Parking/Tree	2
Cycle track	2	Cycle track buffer	0.5
Cycle track buffer	0.5	Cycle track	2
		Tree/furniture	1
Carriageway	6.5	Footpath	2
BRT divider	0.5	Carriageway	6.5
BRT lane	3.5	BRT divider	0.5
BRT station	4	BRT lane	3.5
BRT lane	3.5	BRT lane	3.5
BRT overtaking lane	4	BRT divider	0.5
BRT divider	0.5	Carriageway	6.5
Carriageway	6.5	Footpath	2
		Tree/furniture	1
Cycle track buffer	0.5	Cycle track	2
Cycle track	2	Cycle track buffer	0.5
Tree/furniture	1	Parking/tree	2
Shared lane/footpath	3	Service lane	3

ROW			36m
at station		non-station	
Shared lane/footpath	3	Service lane	3
Tree/furniture	1	Parking/Tree	2
		Tree/furniture	1
Carriageway	6	Footpath	2
BRT divider	0.5	Carriageway	6
BRT lane	3.5	BRT divider	0.5
BRT station	4	BRT lane	3.5
BRT lane	3.5	BRT lane	3.5
BRT overtaking lane	4	BRT divider	0.5
BRT divider	0.5	Carriageway	6
Carriageway	6	Footpath	2
		Tree/furniture	1
Tree/furniture	1	Parking/tree	2
Shared lane/footpath	3	Service lane	3

FEATURES/HIGHLIGHT	Full featured!	42m section minus cycle track
BRT	Two-way with overtaking lane	Two-way with overtaking lane
Carriageway	Two-way	Two-way
Cycle track	Yes	No
Footpath	Partial	Partial
Parking	Yes	Yes
Service lane	Partial	Partial

6.2 Intersection Design

Special intersection treatments are required along BRT corridors in order to reduce delays and maintain system capacity. The aim of junction design for a BRT system is to:

- Minimise delays for the BRT system.
- Provide safe and convenient pedestrian access to stations.
- Minimise delays for mixed traffic.

Junction design will vary according to the volume of turning vehicles, bus operations and volume of pedestrians crossing the junction. In general, BRT junction operation should focus on reducing turning movements across the busway to improve safety and reduce signal delays. As a general rule, signal cycles for BRT intersections should not have more than two phases. Phases that combine BRT and mixed traffic movements can reduce the amount of delay experienced by BRT passengers. Bus priority signals that extend a green phase if the system detects an approaching bus can improve bus speeds on corridors with low bus volumes. However, such systems are not needed on corridors with high bus frequencies.

One way of reducing the number of phases at BRT intersections is to substitute right turns for movements at the network level. For example, right turn can be substituted by three left turns (see **Fig. 22**).

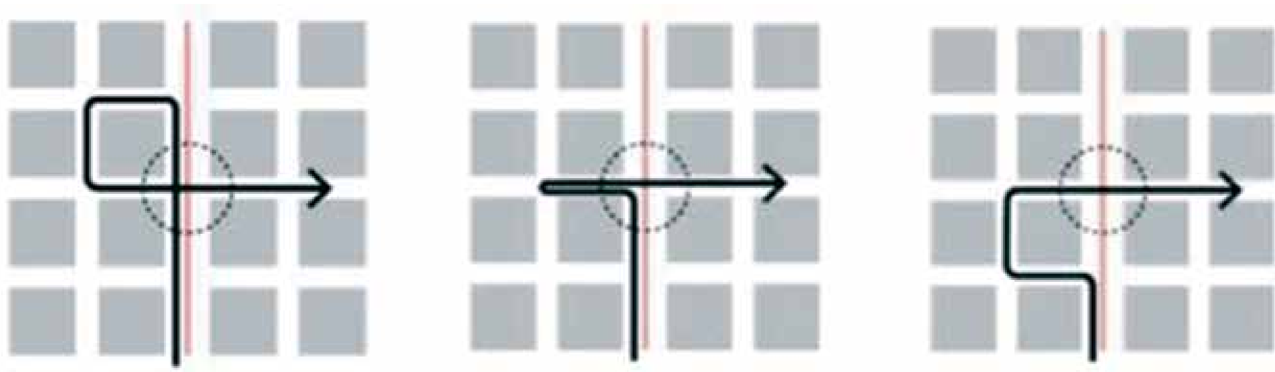


Fig. 22: To reduce intersection delays along BRT corridors, intersections should prohibit right turns for mix traffic. Instead, vehicles can make a series of turns and then cross perpendicular to the corridor.

Photo 23: Forbidding turns across the bus lanes increases bus speeds at intersection: Las Vegas BRT (left) and DART BRT, Dar es Salaam (right).

Signalised roundabouts (also called square-abouts) are a means of managing right-turning traffic at large intersections while minimising signal cycle time. Square-abouts make the right-turn phase obsolete by creating right-turn queuing space within the intersection itself. Vehicles queue in this space during one phase and exit during the next phase. By combining BRT and mixed traffic movements, the square-about accommodates all turning movements in only two phases.

Fig. 23: Signal phases for a signalised roundabout (squareabout) intersection.

Photo 24: Two phase square-about intersection in Ahmedabad.

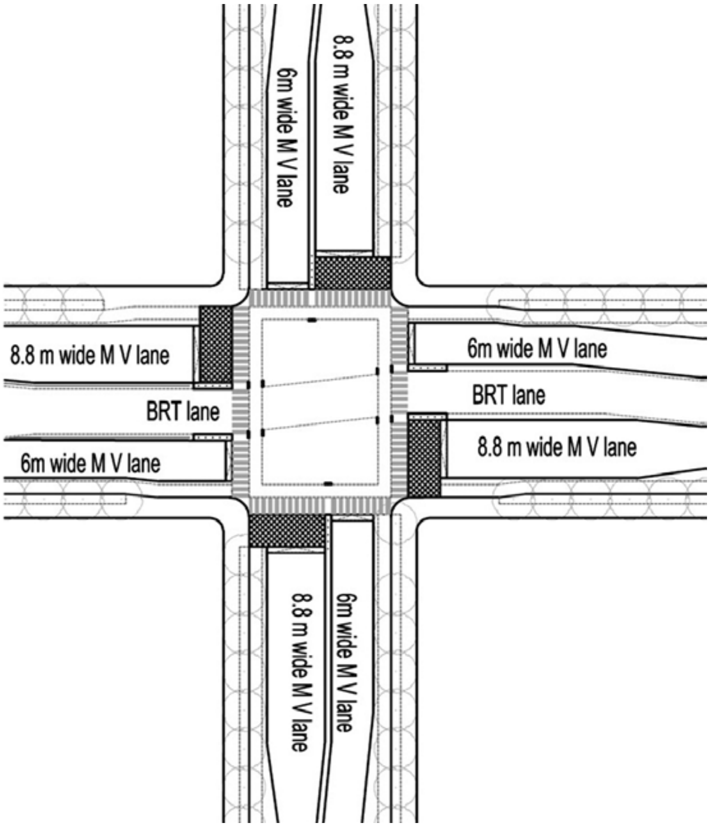


Fig. 24: Typical signalised intersection with BRT.

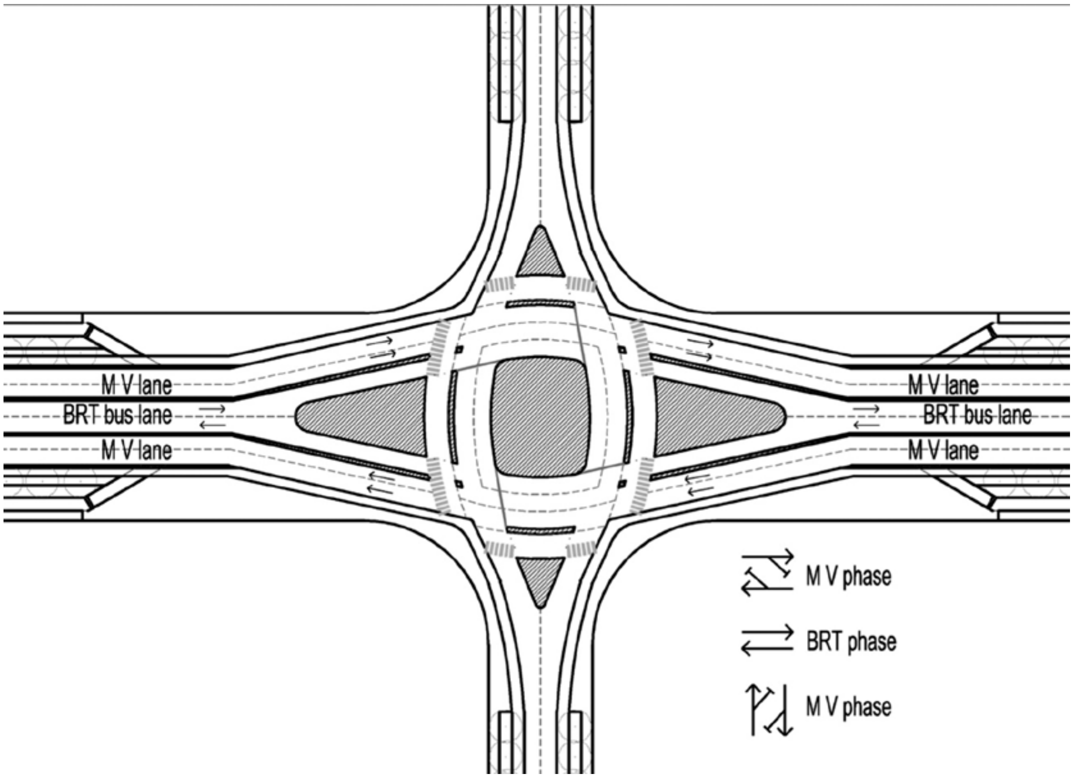


Fig. 25: Signalised squareabout for a BRT corridor with moderate to heavy traffic volumes.

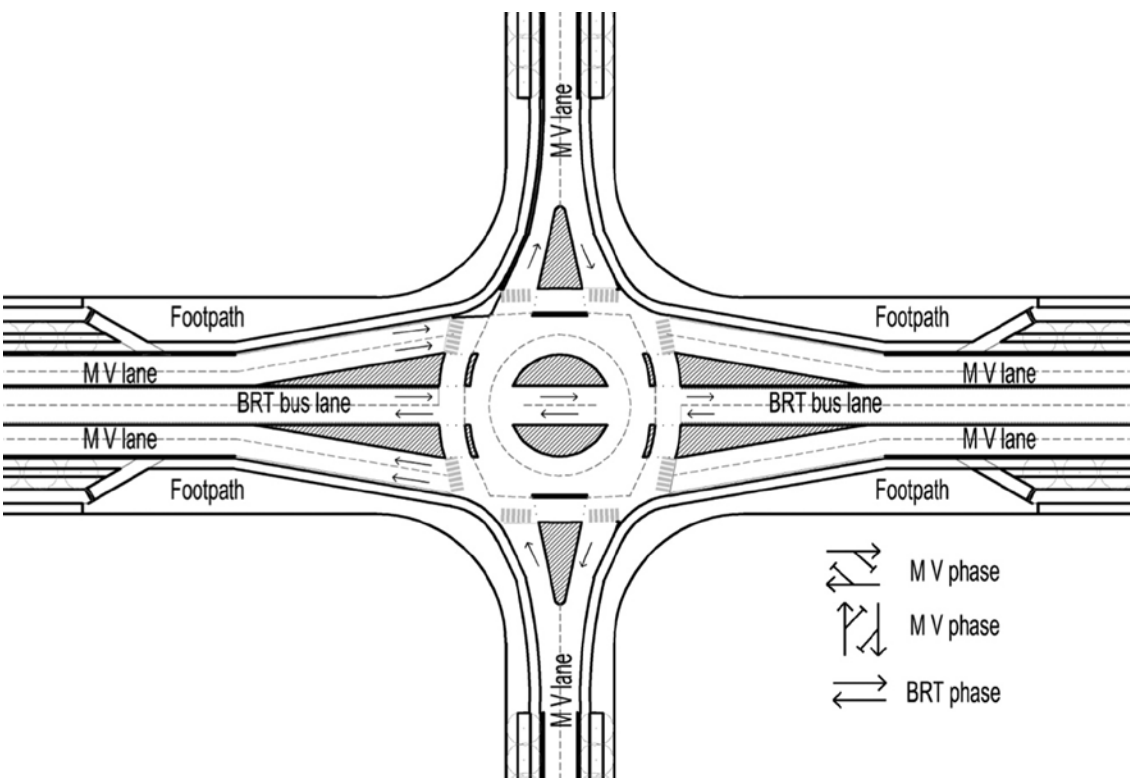


Fig. 26: Signalised rotary with cut-through for BRT corridor

BRT stations should be setback from the intersection stop lines to allow sufficient space for bus and mixed traffic queues. When stations are located immediately adjacent to intersections, significant delays can be caused when a queued bus blocks the docking bay and prevents other buses from accessing the station. The setback distance depends on the frequency of buses on the corridor and the signal cycle duration. Lower frequency and short signal cycles require lower setback. Higher frequency and longer signal cycles require greater queue length, and hence, a larger setback from the intersection. At a minimum, the setback should be equal to the length of two queued articulated buses (~40m).

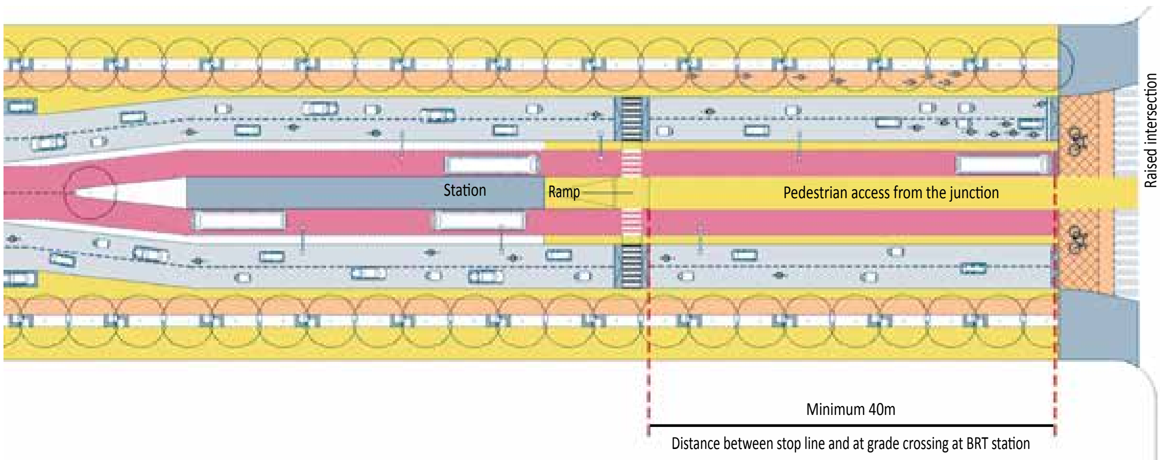


Fig. 27: BRT stations should be offset at least 40 m from intersection stop lines.

Photo 25: Left Image: Station placement exactly at the intersection results in operational inefficiency (Taipei, Taiwan). Right image: Station set-back from the intersection allows buses to queue at the intersection without blocking the docking bays (Guangzhou, China).

6.3 Corridor Management

Traffic along BRT corridors must be monitored and controlled in such a way that BRT operations are not impacted by non-BRT traffic. Effective corridor management depends on close coordination between the traffic police and the BRT agency, as well as dedicated traffic management personnel employed by the BRT operating body. Such BRT-focused traffic police must ensure that junctions are not blocked by traffic regardless of signal activation or intersection design. BRT junction guards are key gatekeepers to the system, and must be vigilant to prevent private vehicles, pedestrians, animals, and others from accidentally entering the busway.

In order to sensitise vehicle users during the initial phase of BRT operations and prevent BRT corridors from encroachment by personal motor vehicles, it is recommended that each corridor has specialised BRT traffic management personnel. The primary duty of these staff is to prevent motorised vehicles from entering BRT lanes and ensure that other vehicles give priority to BRT buses at intersections. In addition, BRT management personnel must work with the traffic police to ensure that footpaths, cycle tracks, and other BRT corridor facilities remain free of encroachments by parked vehicles.

6.4 BRT Corridor Designs for Special Cases

Cities may have to address existing natural or constructed elements while designing BRT corridors. Existing grade separators, canals, and expressways are examples of such elements. BRT corridor designs should be adjusted to address these features through modifications in station locations and BRT lane entry points without hampering basics of BRT.

For example, in Ahmedabad and Pimpri Chinchwad, grade separators have been constructed as split flyovers to accommodate BRT stations without obstructing bus movements. On the Old Mumbai-Pune corridor in Pimpri Chinchwad, BRT designs take into consideration existing grade separated express lanes. BRT stations and lanes have been constructed in the service lanes to facilitate passenger access and to accommodate turning movements of buses at intersections.

Photo 26: In Ahmedabad, a split flyover allows for continuous BRT movement in the median (left). In Pimpri Chinchwad, BRT lanes were constructed in the service lane in order to accommodate existing express lanes (right)

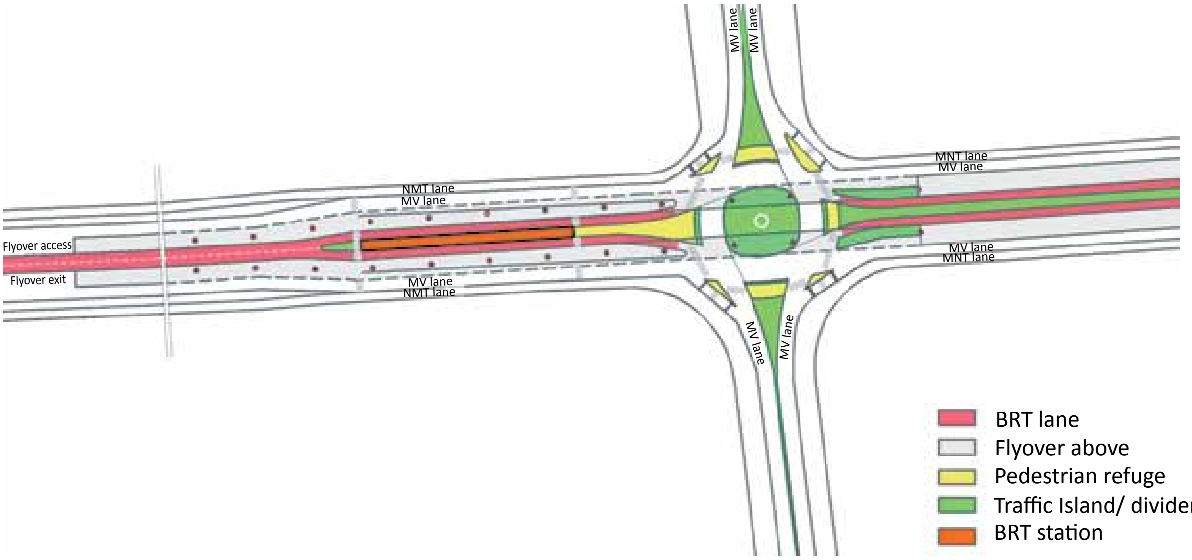


Fig. 28: Split flyovers can help maintaining the continuity of BRT lanes. Below the flyovers, stations are conveniently placed near the intersection and a square-about intersection design allows for a two-phase signal cycle.

6.5 Pavement Design

Good pavement quality ensures better service and operations for a longer period by minimising the need for service interruptions due to busway maintenance. Concrete pavement should be provided for BRT lanes in station areas and at intersections. In these locations, the constant starting and stopping of buses leads to severe rutting if flexible pavement is used. If funding permits, the entire busway may be constructed in concrete. Beyond these provisions, the detailed design of the pavements depends on the axle weight of the BRT vehicles and the projected number of BRT vehicles that are more likely to use the infrastructure over its service life. (Refer to IRC:15 for more information on concrete pavement design.)

Photo 27: Quito BRT utilises reinforced concrete to ensure the longevity of BRT lanes (left). For aesthetic reasons, Bogota utilises brick and paving stones in the city centre (right).

7. UNIVERSAL ACCESSIBILITY

Bus Rapid Transit System (BRTS) not only provides a dedicated corridor for quicker bus and priority vehicle movement, but also provides a segregated and safe corridor for pedestrians and NMVs. The system facilitates access to public transport and also encourages pedestrian trips for short distances. Towards the prioritization of public transport particularly BRTS; stakeholders are investing in renewal of transit and road infrastructure. This creates ample opportunities to make the system inclusive by incorporating universal design features (Rickert, Bus Rapid Transit Accessibility Guidelines, 2007).

Universal design ensures accessibility for BRT passengers and other road users and should be accessible to all irrespective of age, gender and disability. The entire BRT corridor must be designed to provide seamless pedestrian connectivity without abrupt level difference or changes in clear width, which benefits persons with reduced mobility such as people with medical conditions, families with young children, those using mobility aids and persons carrying luggage, pregnant women, etc.

7.1 Footpaths

Footpaths must meet the following standards[11]:

- Footpaths should include a margin next to shop fronts (the “frontage zone”), at least 1.8 m minimum of clear space on footpaths for walking (the “pedestrian zone”), and space for landscaping, lights, bus shelters, signs, property ramps, and other street furniture (the “furniture zone”) (**Photo 28**).
- The minimum clear width of 1.8 m is sufficient for around 1,400 pedestrians per hour in both directions. The width should be increased by an additional half metre for every additional 700 pedestrians per hour.
- Footpaths should be maximum 150 mm above carriageway level.
- Footpaths should have a smooth surface asphalt or concrete.
- Footpaths should be continuous and should not have any level difference at property entrances and intersections. Abrupt and frequent kerb cuts require pedestrians to constantly step up and down and therefore discourage them from using footpaths. Any unavoidable level difference must be bridged with ramps that offer full access to persons with disabilities and those with reduced mobility.
- Tactile pavers should be installed to indicate any change of level, directions and locations where vehicles and pedestrians interact (**Photo 30**).

[11] IRC:103-2012 “Guidelines for Pedestrian Facilities”

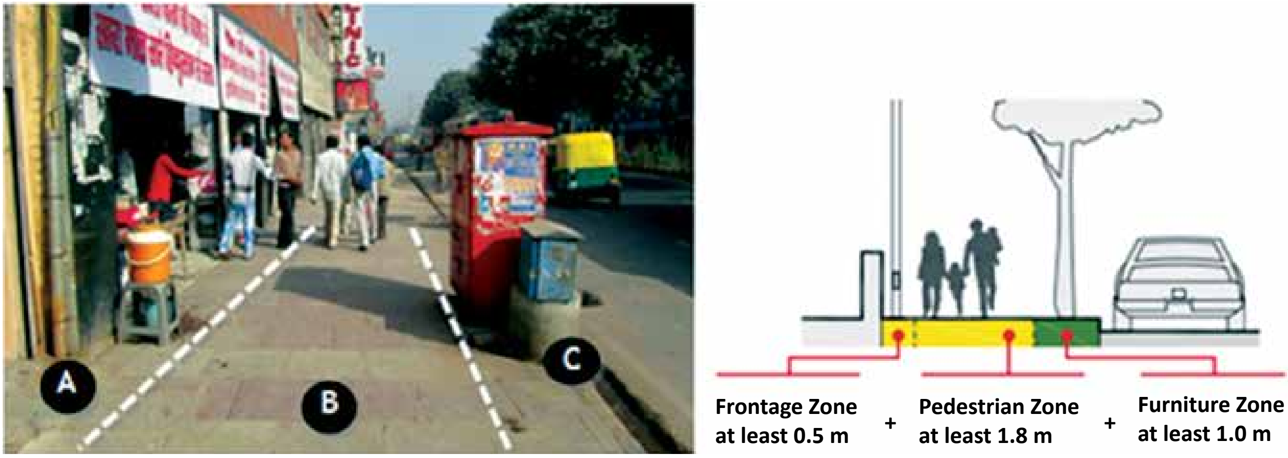


Photo 28: The three main zones of a footpath: Ⓐ the frontage zone, Ⓑ the pedestrian zone, and Ⓒ the furniture zone

Photo 29: Well-designed footpaths have a clear, unobstructed pedestrian zone and a smooth walking surface: Besant Nagar, Chennai (left) and Aundh D P road, Pune (right).

Photo 30: Tactile Pavers (Photos courtesy: SAMARTHYAM)

7.2 Pedestrian Infrastructure

To increase BRTS public transport efficiency, the following measures need to be planned and undertaken during the re-development of entire Right of Way:

Photo 31: Tactile paving on footpath for persons with visual impairments (Photos courtesy: SAMARTHYAM)

- Reconstruction of pedestrian path, service road and medians;
- Widening of corridor cross section for eliminating congestion points;
- Levelled and continuous footpaths having resting spaces and spaces for hawkers at every 200 m;
- Continuous tactile pavers for persons with visual impairments;
- Special white lighting at average 30 lux for footpaths allow the colour contrast of the tactile pavers to be visible during the day and night;
- Route signs and information in Braille;
- Digital display system with audio announcement.
- Raised Table Top for traffic calming and at grade crossing for pedestrians and mobility aid users;
- Bicyclist/tri-cyclist tracks and designated parking for auto rickshaws:
- Way finding and route information signage in contrast colour and large fonts
- Crossings and intersections-auditory signals and accessible median refuges

7.3 Passenger Access

Well-designed crossings allow pedestrians to go across busy streets safely and conveniently. For BRT to function well, people must have safe access to stations. At-grade crossings are the preferred mode of access for BRT stations. Pedestrian foot over bridges are acceptable only in the case of BRT corridors located on limited access highways. Such bridges may have working elevators and escalators. Pedestrian crossings at BRT stations must meet the following standards:

- A raised crosswalk that is at least 2.4 m wide should be provided, elevated to the level of the adjacent footpath (150 mm above carriageway) with a speed table for motor vehicles. The slope for vehicles should be in a range from 1:8 to 1:15 (**Fig. 29**).[12] Grade separated pedestrian access (foot over bridge/ subways) should only be provided in case of expressways. Pedestrians should not have to cross more than two lanes of traffic before reaching a pedestrian refuge. Otherwise, a signalised crosswalk should be provided.
- Speed bumps in mixed traffic lanes in advance of pedestrian crossings can help reduce motor vehicle speeds further.

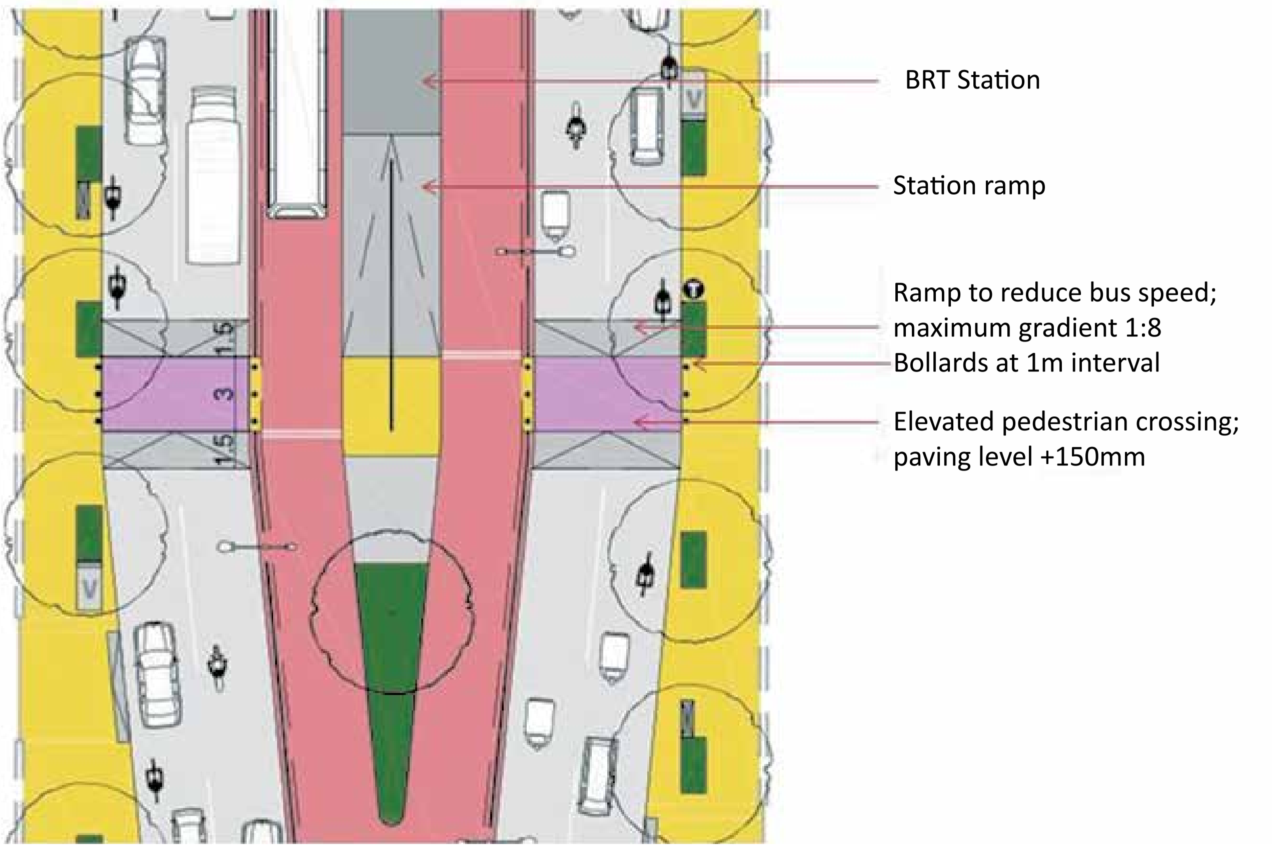


Fig. 29: Raised crosswalks at station area

12 Bus lanes should be ramped up to the level of the raised crossing but at a more gradual slope than that employed in mixed traffic lanes. The BRT lane can remain at 150 mm for the entire length of the BRT station, with a final down ramp provided after the pedestrian crossing at the other end of the station.

Photo 32: Safe at-grade pedestrian crossings, in Dar es Salaam (left), are preferred as they provide easy, convenient access to BRT stations. On highways corridor such as in Istanbul (right), foot overbridges can be considered

7.4 Station Ramps

Station ramps must meet the following standards:

- Ramp gradients should not exceed 1:15.
- The materials selected for the surface finish of a ramp should be firm, levelled and easy to maintain. These must also be slip resistant, especially if surfaces are likely to become wet.

Photo 33: Ramps at stations should have a 1:15 gradient max. and handrails at two levels on both sides of the ramp (Photos courtesy(R) SAMARTHYAM)

Photo 34: Station ramps enable all users to access the system comfortably (Rainbow BRT, Pimpri Chinchwad)

7.5 Bus Interior

The interior of BRT vehicles must also be designed so that all persons can use them. The following access features must be included on all BRT vehicles (over and above the standard urban bus specifications) :

- Stanchions, grab bars and hand-holds must be provided in contrast colour for balance and support for passengers to hold during bumps or sudden stops that the vehicle may encounter.
- Priority seating must be provided that is clearly identified as being reserved for people with disabilities, seniors, and mothers with small children, or pregnant women.
- Approximately 800 mm x 1200 mm of space on BRT vehicles must be dedicated for persons using mobility devices. This area must be located adjacent to vehicle entry doors to facilitate access from BRT stations.
- Stop request buttons must be installed at locations of priority seating and wheelchair positions.
- Auditory announcements of stop names and key destinations ensure that people who are visually impaired are facilitated to reach their destinations.
- For BRT and feeder buses operating on service extensions beyond the dedicated BRT corridors, a manual ramp or lift must be provided so that

conductors can provide assisted boarding from bus stops and from the ground level for seniors, wheelchair users, and other people with physical disabilities.

7.6 Bus Stops on Service Extensions

BRT trunk buses in a hybrid system as well as feeder buses in a closed system travel beyond dedicated BRT corridors. Along these extensions, stops will be provided on the kerb at the left side. Bus stops should be placed adjacent to the linear line of travel so that the bus does not need to pull over to the left (IRC:103, 6.10). Bus bays should be avoided because they increase travel time for bus users and the likelihood that bus passengers will stand in the street while waiting for the bus. The position of the bus stop should always leave accessible clear space for pedestrians behind the shelter.

If BRT services utilise high-level boarding platforms (e.g., 650 mm or 900 mm), a lift must be provided on the left side of the bus. In the case of low-floor buses, an automated or manual hinged ramp can bridge the level difference between the bus floor and the bus stop. Bus stops should be built at a height of 150 mm (i.e., the same height as the surrounding footpath) to improve accessibility and safety if buses do not pull directly up to the kerb.

8. VEHICLE SPECIFICATIONS

In general, standard 12 m BRT buses should have doors on the right side of the bus to allow for level boarding and alighting from median stations. Each door should have a width of at least 1.2 m minimum, and the doors should be separated by at least 400 mm. On higher demand corridors, 18 m articulated vehicles enable an increase in capacity without increasing station saturation. These buses should have four wide doors on the right side at the same level as the station floor.

In closed systems, trunk services can be operated with high floor buses because passengers only board from BRT stations. For systems with direct services, buses need to have doors on the left side that allow for kerbside boarding and alighting when the vehicle leaves the dedicated lanes. Low-floor buses with hinged manual wheelchair ramps are generally preferred for systems operating direct services because they are accessible to persons with disabilities on service extensions. In case of systems with dual-side stations in each direction, trunk services can use high-floor buses while direct service routes can use low-floor buses.

In case of corridors with very high demand, articulated and bi-articulated buses are preferred. It should be noted that the cost of such buses in low-floor configuration tends to be 5 to 6 times that of a high-floor configuration of a bus with same length. Therefore, systems designers are encouraged to create a closed system where high-floor articulated and bi-articulated buses provide trunk line services while low-floor buses of smaller size (8 to 12 m) are used for feeder services.

Table 7: Preferred Bus Floor Height for Different BRT Service Typologies

Service type	Closed BRT system	Hybrid BRT system
Trunk	High floor (preferred because of cost savings) or low floor	High floor / Low floor
Feeder	Low floor	Low floor
Direct	-	Low floor

Table 8: BRT Bus Capacity

Vehicle type	Vehicle length (m)	Capacity
Standard	12	70
Articulated	18	150
Bi-articulated	24	210

Buses should meet modern emissions norms (i.e., at least Bharat Stage IV). However, the primary emission savings from BRT systems typically come from the reduction in kilometres travelled by personal motor vehicles rather than the marginal reduction in the emissions from each bus. BRT buses should be compliant with the urban bus design standards as developed by Automotive Industry Research Committee of Ministry of Road Transport & Highways and Ministry of Housing and Urban Affairs. Buses may also be designed with attractive external styling and high-quality interiors to project a smart image for the system.

Photo 35: A 12 m standard BRT bus in Rainbow, Pune (left) and an 18 m articulated bus in Transmilenio, Bogotá (right).

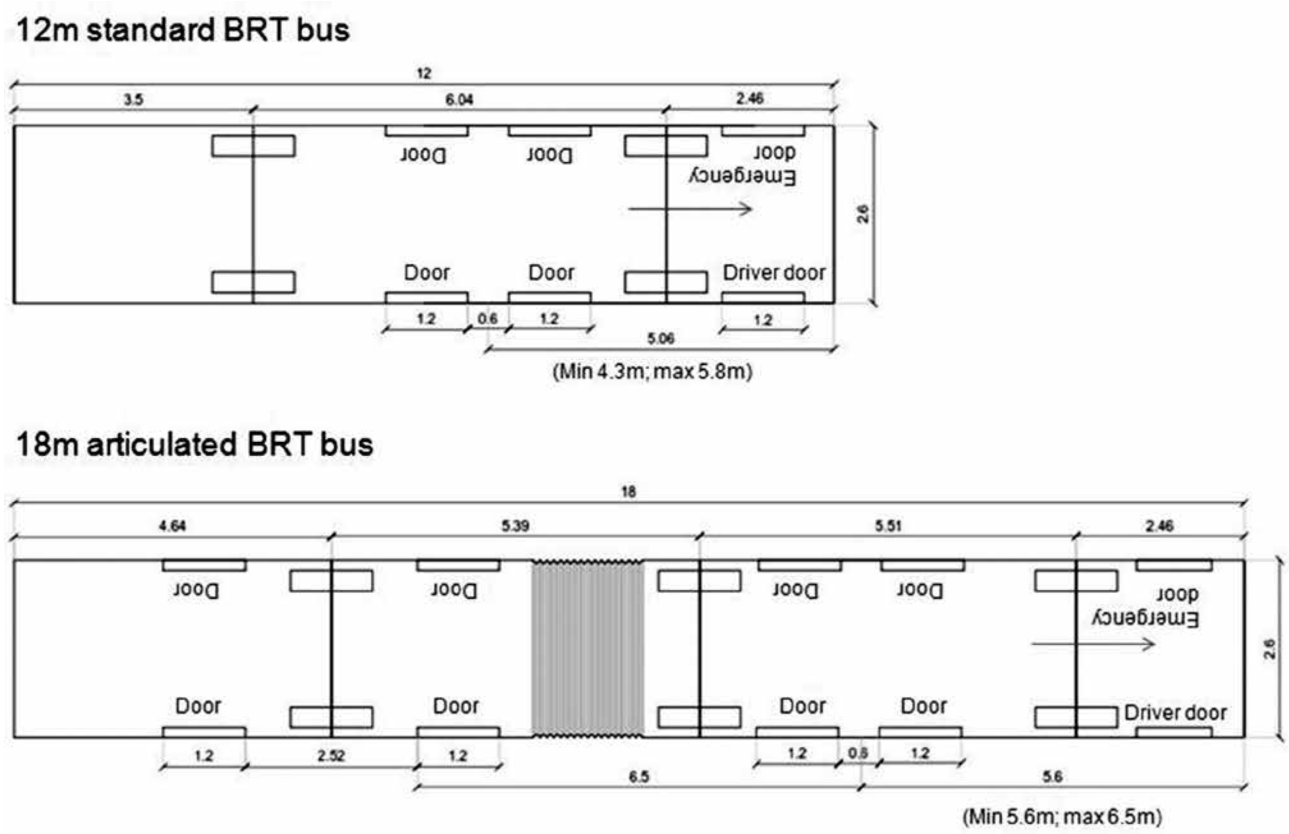


Fig. 30: Location and width of doors on 12 m and 18 m bus.

Table 9: 12 m BRT Bus Specifications as per UBS II Guidelines

Component	Specifications
Length	12 meters
Width	2.6 meters
Height	3.8 meters
Wheel base	6.1 meters
Turning radius	As per IS: 9435 - 1980
Front overhang	Not more than 45% of wheel base
Rear overhang	Not more than 50% of wheel base
Axle clearance	Min. 190 mm
Min. Ground clearance	Within wheel base, not less than 270 mm
Min. interior headroom	1900 mm
Gangway	800 mm
Passenger Capacity	32-34 seated and 34-38 standees
Seat layout	2 x 2

Seat space per passenger	400 * 350 mm (width * depth)
Seat material	PPLD/LDPE moulded AIS 023
Height over sitting area	> 900 mm
Door type and height	Double jack type, minimum 1900 mm
Clear door width	1000 mm (in open position with flap gates)
Operation time in second	Less than or equal to 4 seconds
Doors for BRT operations (right side)	Entry and exit doors to be 1000 mm wide each (in open position with flap gates)
Width of partition between BRT gates	At least 400 mm
Door Operations	Electro-pneumatically controlled
Load capacity	70 passengers
Unloaded bus weight	Not more than 10 tonnes
IT Systems	Bus architecture should be compatible to install IT systems like LED destination boards on front, rear and left side of the bus as well as one internal LED board behind driver seat. GPS and other related equipment for bus tracking, two-way communication and on-board bus unit should be able to be installed.
Fuel	Diesel, CNG
Max. Speed	Less than or equal to 75 km/h.

9. SAFETY

Well-designed BRT systems hold the potential to improve safety for all road users. Since dedicated BRT corridors segregate buses from smaller vehicles, they can result in a good reduction in minor as well as major crashes. With appropriately designed pedestrian facilities, conflicts between motor vehicles and pedestrians can fall as well. Safe design of BRT requires attention to the following safety elements:

- **Physical segregation of BRT lanes:** Physical barriers between the carriageway and BRT lanes help prevent conflicts between mixed traffic and BRT buses. Railings are advisable to prevent random pedestrian crossing movements along the corridor. However, breaks in the railings should be provided at regular intervals to facilitate safe crossing behaviour.
- **Intersection design:** The layout of intersections should facilitate safe user behaviour. Channelisation using medians and pedestrian refuge islands can

help reduce crossing distances, streamline traffic flow, and reduce avoidable conflicts.

- **Pedestrian crossings:** BRT corridors require safe pedestrian crossings at regular intervals. Pedestrian crossings should be built at grade to ensure that they are accessible to all users. Crossings require adequate markings and signage. Motor vehicle movements must be managed, either through signalisation in the case of crossings located at junctions, or through physical traffic calming elements at mid-blocks. Mid-block crossings should be constructed as table-top crossings that are raised to the level of the adjacent footpath. Bollards, if provided should have minimum spacing of 1 m to allow mobility aid users such as wheelchairs to pass through unhindered.

Photo 36: Inadequate spacing of bollards and level difference at crossings (Photo courtesy SAMARTHYAM)

- **Footpaths and cycle tracks:** The corridor design must provide for safe movements for pedestrians and cyclists through the length of the corridor. Wide, continuous footpath and cycle tracks are important to provide access to BRT stations and to offer access to other road users.
- **Driver training:** Adequate training is required to orient and sensitise drivers to BRT corridor safety issues.
- **Level boarding:** Precision docking of buses and level boarding is essential for the buses so that there is minimum horizontal and vertical gap between bus platform and bus chassis (**Photo 37**), which can be bridged through manual hinged ramp.

Photo 37: Level Boarding BRT Delhi (Photo courtesy SAMARTHYAM)

- **Traffic management:** During the initial phase of BRT operations, in order to sensitise vehicle users and promote safe road user behaviour along a corridor, traffic wardens should be stationed at major junctions and pedestrian crossing points along the entire corridor. The primary duty of these guards will be to prevent motorised vehicles from entering the corridor, ensuring that vehicles give priority to BRT buses at intersections, and providing safety to pedestrians who wish to cross the road or access a BRT station.

Once the system is operational, the BRT control centre should monitor all traffic incidents along the corridor to document safety issues and identify solutions.

10. BRT OPERATIONS

Following implementation, BRT operations should be monitored closely to ensure good performance. BRT is more than the physical infrastructure of bus lanes and stations reliable service and customer friendly operations are equally essential to the success of a system. Long-term system management is more likely to succeed if a BRT system is operated by an empowered agency with qualified professionals and trained staff.

10.1 System Monitoring

To facilitate effective ongoing management of a BRT system, it is advisable to create a professional, robust management body to oversee the system. Known as a “Special Purpose Vehicle” (SPV), this body is responsible for planning, managing, and monitoring BRT operations. The SPV need not operate services directly, but can engage a number of private contractors to operate various elements of the BRT system. For instance, the SPV can hire a bus operator to procure the BRT buses; hire drivers and maintenance staff, and operate BRT services according to a schedule provided by the SPV. The involvement of private operators helps leverage the government's investment in the system by bringing in private capital to finance elements such as buses and fare collection equipment.

The SPV needs qualified, professional staff and the independence to make swift decisions during the implementation process. The staff is responsible for carrying out a range of activities, including project implementation; procurement of services; operations management; financial management; communications and marketing; and planning of future phases. Active monitoring of system performance, passenger demand, and safety incidents by the SPV helps ensure that system operators meet stipulated service level standards and provide excellent customer service.

For cities with SPVs for public transport operations, a separate BRT cell with qualified and full time staff should be created. The SPV or cell should receive urban transport fund collected from various sources of revenue such as fare, non-fare-box, parking management etc. At least 10% of the received fund shall be utilised for the maintenance of existing BRT infrastructure.

10.2 Fare Collection

Efficient fare collection is an essential component of a modern public transport service. Most BRT systems make use of off-board fare collection with electronic smart cards to improve customer experience and reduce revenue leakage. Off-board fare collection eliminates delays such as those caused when buses halt between bus stops to allow a conductor to sell tickets to all of the passengers on the vehicle. They also eliminate the need for passengers to fish for change on a moving vehicle. Off-board fare collection with smart cards is the dominant form of fare collection in BRT systems worldwide for the reasons described in the following sections and summarised in **Table-10**.

Table 10: Comparison of Fare Collection Options

Parameter	On board fare collection with paper tickets	On board fare collection with smart card validator	Off board fare collection with paper ticket (without access control)	Off board fare collection with smart card validator (with access control)
Capital cost	Low	Moderate	Low	High
Manpower cost	High	Low	Moderate/High	Low
Potential for revenue leakage	High	Moderate	Moderate	Low
Time to issue ticket (or fare validation)	High	Moderate	High	Low
Impact of ticket inspection on system speed	High	High	Low	Low

10.2.1 *Fare types*

The fare type for a BRT system should take into account land use patterns, passenger trip lengths, and capital cost factors. There are following five types of fares:

- **Flat fare:** In this type, a passenger is charged with the flat rate for his journey irrespective of the distance travelled or origin and destination. Flat fares are advantageous from a social equity perspective. Flat fare scan permit multiple transfers within a prescribed time limit.
- **Distance-based fare:** Distance-based fares vary based on the number of km travelled by the passenger. In a distance-based fare system, the fares paid by customers closely match the actual operating costs incurred to the system.
- **Zone-based fare:** A zone-based fare is a simplified version of a distance-based fare. Zone-based fares incorporate some variations according to distance but can be easier for passengers to understand.
- **Time-based fare:** Time-based fares are typically employed in the form of passes that allow unlimited daily, weekly, monthly or quarterly trips for a fixed fare. Sometimes, passes allow unlimited trips but only between known origin-destination stops or within fixed set of zones. Time-based fare may also be employed for shorter duration, i.e., up to 1 or 2 hours.

BRT systems may have combination of fare systems. For example, trunk routes may have a distance-based fare, while feeders have a flat fare. However,effective passenger information is essential to explain the fare rules if more than two systems are employed.

10.2.2 *Fare media*

While off-board fare collection can be accomplished with paper tickets, electronic fare collection using RFID smart cards has many advantages for BRT systems, including reduced need for ticketing staff, higher revenue retention, and time saved because passengers do not need to queue at ticket counters each time they ride the system. RFID cards contain an electronic chip that can read and process information regarding cash inputs and can permit the collection of a wide range of information on commuter movements. A smart card system should also be designed so that it can serve multiple transport modes and essentially function as a common mobility card across the whole region.

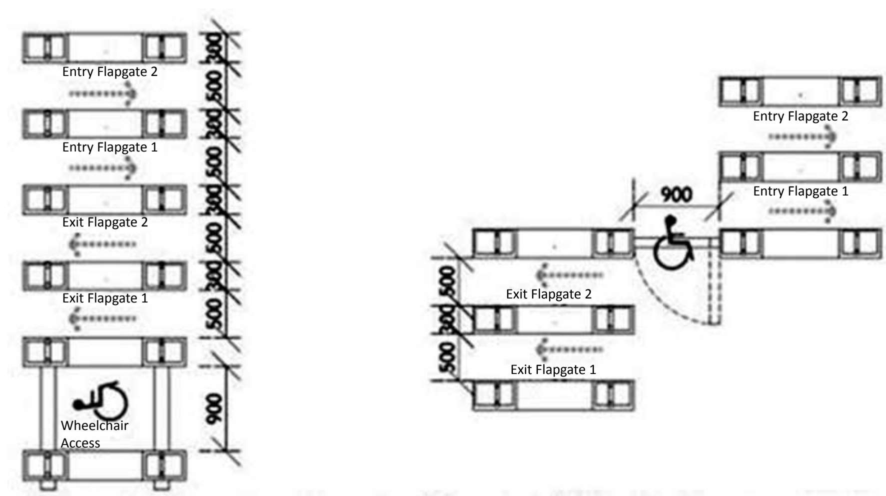
Photo 38: Flapgates and smart card readers control entry into stations and reduce fare evasion: Yichang BRT (left), Chengdu (right).

10.2.3 *Access control*

Automatic barrier control at BRT stations reduces the amount of time needed to verify fare payments. Most contemporary rapid transit systems in India including metro systems in Delhi, Mumbai, Bengaluru, Chennai, and Jaipur as well as the BRT system in Ahmedabad use flap gates. These gates fold back automatically once the fare reader completes a successful reading of an electronic smart card.

Flap gates can provide advanced detection systems that prevent the gates from closing when a stroller or suitcase is still passing through the gate. The flap gate can still stay open if another legal passage is detected. Further, the design of wing gates can allow for wider gates that permit the passage of wheelchairs.

The tripod-shaped turnstiles used in many older rapid transit systems have lower operating and maintenance costs compared to flap gates. However, tripod gates are not universally accessible to persons with disabilities and users with strollers and heavy luggage. Furthermore, flap gates offer faster throughput because the users can simply walk through the gate without applying physical force to turn the tripod unit.



Access barrier arrangement for wide terminals | **Staggered turnstile arrangement for narrow terminals**

Fig. 31: Flap gate arrangements for BRT stations.
A staggered turnstile arrangement is preferred for narrow stations.

10.3 Passenger Information

One of the barriers to using public transport is customer uncertainty about when the next bus will arrive. Providing real time information in the form of voice communications and variable message signs at stations can eliminate this uncertainty for BRT users. Real-time information services should include:

- **At stations:** visual and audio announcements of when the next bus will arrive and the destination or route number of the bus.
- **On buses:** real-time audio and visual announcements of the next stop and the final destination of the route.

In addition to the real-time information, the following static information must be provided:

- **At stations and terminals:** route map, fare chart, directions, system map, station locations, and an area map with surrounding landmarks;
- **On buses:** route diagrams;

Multi-lingual real-time and static information is preferred to allow for easy comprehension by all users.

Photo 39: Real-time information at stations in Rainbow, Pimpri Chinchwad (left), and inside buses such as in Jinan (right) is critical to a positive overall experience of passengers.

10.4 Fleet Management and Scheduling

The aim of fleet management is to ensure that the services are run according to schedule and to address problems such as delays due to traffic congestion. Some of the key requirements of a fleet management system are the ability to locate a vehicle and to transmit this information to the control centre. Most fleet management systems use vehicle location information to inform various functions such as real time monitoring, real time passenger information, and service planning.

Operational data can be stored as part of a record of operations and may also be analysed to review operational performance. The comparison of the planned and actual services provides important information not only for the service operator but also for the government agency letting the service contract. Further, inclusion of parameters such as fuel consumption and engine performance makes it possible to calculate both the financial and environmental impact of running the BRT services. Logging of parameters such as acceleration, speeds, and braking provides a basis for generating feedback on driving behaviour. For maintenance tracking, the system can keep a record of all vehicle failures, defects, inspections, modifications, and repairs. The data in the maintenance control report should also provide a basis for analysing failure trends and informing maintenance schedules.

11. INTER-MODAL INTEGRATION

For BRT to function as part of a coherent public transport network, passengers need to be able to transfer easily from one mode to another. Integration does not merely mean placing stations for multiple public transport modes close together. Rather, it involves the detailed design of inter-modal stations incorporating the following features:

- Short, direct walking paths with minimal level difference for transferring passengers.
- Adequate clear space for passenger movement to prevent bottlenecks.
- Protection from sun and rain.
- Public information.

Some inter-modal facilities, such as auto-rickshaw and cycle rickshaw stands and cycle parking, can be developed at several major stations along a BRT corridor. Convenient inter-modal facilities should be developed wherever the BRT corridor passes near a metro station, intercity rail station, city bus hub, or intercity bus terminal.

Photo 40: Passengers on Medellín's Metroplus BRT corridor can easily access the city's elevated metro line via a staircase without leaving the station.

12. DEPOT LAYOUT DESIGN

BRT depots should include areas for refuelling, cleaning, repairs, administration, and parking. Depots are generally located at or adjacent to terminal facilities so that depot parking can be used for BRT vehicles coming out of service during off-peak periods.

The location of a depot is often dependent upon the economical acquisition of sufficient property, but depots generally should be sited immediately adjacent to a BRT corridor to reduce the number of "dead kilometres" that buses operate to reach a corridor end point. The geometric design of the depot entry should be designed in conjunction with that of the BRT corridor. The interior layout should allow for convenient manoeuvring of buses.

The size of the depots and terminals depends on the number of vehicles that will be based at the depot. As a thumb rule, a depot for 100 standard buses requires approximately 2 hectares. Depot surfaces should be constructed in concrete rather than asphalt for better durability.

Photo 41: BRT depot facilities in Surat (left) and Bogota (right).
(Photos courtesy: Arya Architects and ITDP)

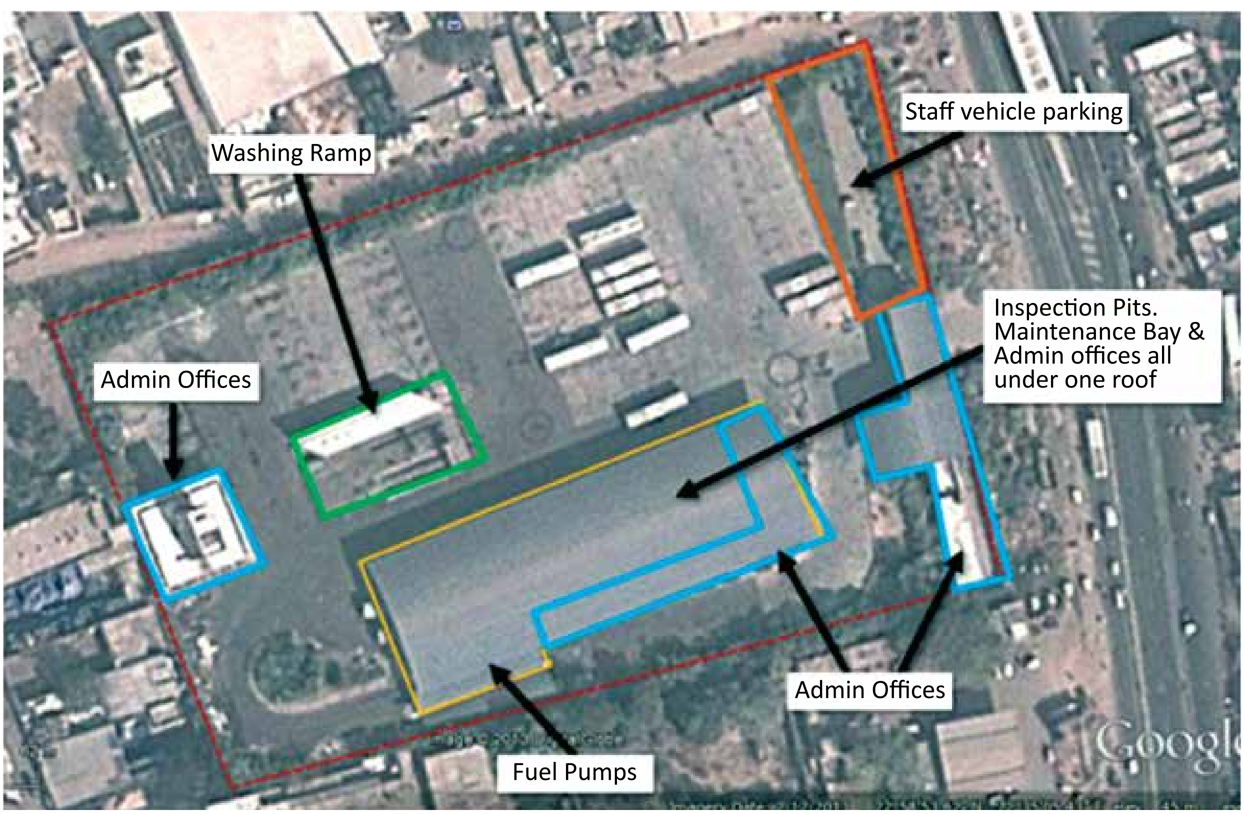


Fig. 32: Chandola BRT depot, Ahmedabad

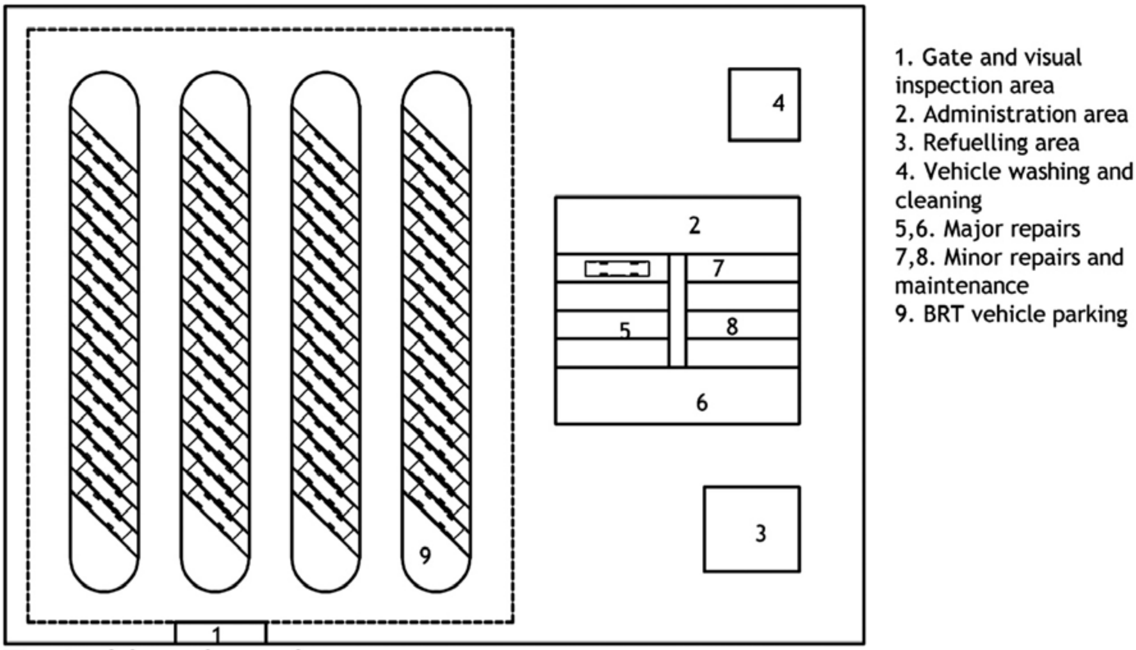


Fig. 33: Typical bus depot layout

13. PARKING MANAGEMENT

Unmanaged corridors with chaotic illegal parking, unrestricted street vending as well as encroachments by various activities are the norm on most streets in Indian cities. While many cities have taken steps to regulate and manage street vending through clearly defined policies, on-street parking remains haphazard and unmanaged. Following are the broad principles of parking management for cities :

- **Prioritise sustainable modes of transport.** Cities must make transport planning decisions that give priority to facilities for sustainable modes of transport over parking, both on the street as well as off the street (such as intermodal facilities). Provide feeder connections and improve intermodal integration between various public transport modes. Cities must prioritize sustainable modes of transport (walking, cycling, public transport) in their financial plans.
- **Price parking to manage demand.** Instead of trying to increase parking supply, cities must treat parking as a commodity that should be priced proportional to demand. While determining parking rates, cities must ensure that streets with higher parking demand must have higher parking fee. Parking rates must be based on location, time of day, duration of parking and category of vehicle (defined by size and type). Prices for on-street parking must be higher than off-street parking to encourage people to use off-street facilities and free up road space for other uses.
- **Manage and enforce on-street parking first.** Even when off-street parking is available to users of personal motor vehicles, it is often under utilised due

to the low or no cost of on-street parking and poor enforcement. Thus, cities must manage and enforce on-street parking effectively before building any off-street parking facilities, public or private.

- **No subsidy to parking.** Cities must not subsidize on-street or off-street parking for personal motor vehicles (including multi-level parking), implicitly or explicitly. Where private sector develops off-street parking for personal motor vehicles, the private sector must bear the full cost of land, construction, maintenance, and operations, and recoup its investment directly from parking users without any form of cross subsidy using public funds. Cities must ensure that users pay full cost of parking facility based on opportunity cost of land, capital cost, O&M cost and temporal demand.
- **Parking revenue for sustainable modes of transport.** Cities must earmark the revenue from parking management for investments in sustainable modes of transport. Specifically, cities must develop mechanisms whereby a good portion of the parking revenue from an area of the city is spent on improving walking, cycling and public transport facilities within that area. Estimates show that revenue generated by 1 km of paid parking can pay for not just the creation and maintenance of high quality footpaths along the stretch but also the addition of up to ten new buses to serve the area.
- **Limit parking supply.** Cities must limit total parking supply, including public and private off street and on-street parking based on the capacity of the road network in the zone. Cities must set caps on the total quantum of parking available in each zone. Construction of additional off-street parking spaces (public as well as private, including multi-level car parking) facilities must be balanced with a reduction in on-street parking. For example, in 1996, the city of Zurich in Switzerland capped parking supply at 1990 levels, to prevent addition of extra parking in the city centre that might result in increased congestion.
- **Create active street frontage.** Parking in the front setback creates an undesirable separation between footpaths and activity within buildings. Further, stilt parking on the street facing edge of buildings create an inactive and potentially unsafe spaces. Cities must modify building regulations to ensure active edges and prohibit parking in the front setback.

14. SYSTEM EVALUATION

14.1 Design Evaluation

The following checklist can be used to evaluate whether the design of a BRT system includes good practice features that contribute to good system performance. The scorecard can also be applied to rail-based systems such as metro systems with minimal modification.

Table 11: Design Evaluation Criteria

Topic	Criterion
Dedicated right of way	Physically segregated lanes are provided for BRT buses.
Busway alignment	BRT lanes are aligned in the middle of the roadway.
Off-board fare collection	Fares are collected at stations rather than on the bus.
Intersection treatments	Intersections have at most two phases, with right turns across the busway prohibited or alternate schemes like signalised roundabouts incorporated.
Platform level boarding	The floor level of buses is the same as the floor of stations.
Minimising bus emissions	Buses meet at least Bharat Stage IV emissions norms.
Stations set back from intersections	Stations are set back at least 40 m from intersections.
Centre stations	Passengers board from median stations serving both directions of service.
Pavement quality	Busways are built using rigid pavement, at least at stations and intersections.
Distance between stations	The distance between stations is between 300 and 800 m.
Safe and comfortable stations	Stations are comfortable, attractive, and weather-protected.
Number of doors on buses	Buses have at least two wide (i.e., at least 1.2 m) doors in the case of 12 m buses and three wide doors in the case of 18 m buses.
Docking bays and sub-stops	Stations have at least two docking bays. In the case of high demand systems, major stations have at least two sub-stops.
Sliding doors in BRT stations	Stations have sliding doors at boarding points.
Branding	The system has consistent branding across stations, buses, and other facilities, including a unique name and logo.
Passenger information	Stations and buses provide static and real-time passenger information.
Universal access	All buses, stations, crossings, refuge islands, and footpaths are accessible to persons with disabilities and reduced mobility .
Integration with other public transport	The BRT system is integrated with other public transport modes, both in terms of fare as well as physical infrastructure.
Pedestrian access	Footpaths with at least 2 m of clear space for walking are provided along the entire corridor.
Secure cycle parking	Stations offer secure parking for cycles.
Cycle sharing integration	Cycle sharing services are offered along the BRT corridor.
Corridor located	The BRT corridor is located on one of the top ten highest demand corridors in the city.
Demand profile	BRT infrastructure extends into the highest demand segments along the corridor
Multi-corridor network	The BRT system includes multiple existing or planned corridors.
Passing lanes at stations (for high demand systems)	Passing lanes allow buses to overtake buses that are docked at stations.

14.2 Performance Evaluation

Once a BRT system is operational, the following checklist can be used to evaluate whether management practices along the corridor are contributing to good performance.

Table 12: Performance Evaluation Criterion

Topic	Criteria
Multiple routes	The corridor has two or more services.
Control centre	The system has a functioning control centre that monitors bus movements, responds to incidents real-time, controls the spacing of buses, and trip data for each bus, including distance travelled and speed.
Hours of operations	The system offers late night and weekend service.
Commercial speeds	The system offers commercial speeds of at least 20 km/h.
Passenger throughput	The system serves at least 2,000 pphpd.
Passenger boardings	Number of daily passengers.
Load factor	Passenger kilometres travelled divided by bus kilometres travelled.
Transfer rate	Passenger boardings divided by linked passenger trips.
Enforcement of right-of-way	Effective enforcement measures prevent unauthorised entry of mixed traffic into the busway
Significant gap between bus floor and station platform	The horizontal and vertical gaps between the station platform are at most 10 cm and 5 cm, respectively).
Overcrowding	No more than 25 per cent of peak hour buses experience loads of over 5 passengers per sq. m
Maintenance of the busway, buses, stations, and technology solutions	BRT facilities are clean, free of litter, and in a good state of repair.
Frequency	Each service operating on the BRT corridor has a frequency of at least 8 buses during the peak period and 4 buses off-peak.
Express, limited and local services (for high demand systems)	The system offers limited or express services that skip some stations.

15. CHECKLIST FOR BRT INFRASTRUCTURE AND OPERATIONS MANAGEMENT

Element	Mandatory	Recommended
Station interiors:		
BRT station platform same as BRT bus height	Y	
Docking ledge (200-250 mm) with rubber beading	Y	
Automated sliding doors	Y	
RFID tags for sliding door operations	Y	
Vertical alignment marker (flag) on the station edge for bus docking	Y	
Kassel kerb		Y
Electricity connections	Y	
Lighting arrangement	Y	
UPS (electricity backup) facility	Y	
Solar panels for station electricity		Y
Fixtures for PIS displays	Y	
PIS board at stations	Y	
Tactile flooring	Y	
Passenger seating	Y	
Stop line and entry/exit arrows to guide passengers at the station automated doors	Y	
Sufficient number of docking bays based on demand	Y	
Station name displayed - internal	Y	
Station name displayed - external	Y	
Corridor map, transit map displayed	Y	
Route-wise headway information displayed inside stations	Y	
Station kiosk for off-board fare collection		Y
Ticket prices displayed		Y
Local area way finding map displayed		Y
Station doors/shutters at main entry- for security at night	Y	
Concrete surfacing installed in bus lanes		Y
Concrete surfacing installed at least near stations- bus docking area	Y	
Passing lanes (wherever applicable)		Y
Small railing/barrier on both the edges of the ledge for safety		Y
Corridor design:		
Corridor segregation	Y	
Footpaths on either side of the corridor	Y	
Pedestrian refuge islands between bus lanes and mixed traffic lanes	Y	
Tabletop crossing in mixed traffic lanes at midblock locations	Y	
Zebra markings	Y	
Table top crossing- Speed bump ahead in the direction of traffic	Y	
Lane segregation at bus station installed	Y	
Designated stopping bays for auto rickshaws/cycle rickshaws share autos near stations (wherever applicable).		Y
Terminal entry-exits are designed properly	Y	
Wide and safe universally accessible footpaths along the corridor as per IRC:103-2012	Y	

Element	Mandatory	Recommended
Wide and safe universally accessible footpaths on access roads to corridor at least up to 500 m from stations as per IRC:103-2012	Y	
Sufficiently wide bicycle lanes along the corridor-wherever applicable		Y
Corridor enforcement signage	Y	
Intersections:		
Bus lane segregation up to the junction	Y	
Minimum 1.2 m wide Pedestrian refuge islands at medians on all arms	Y	
Pedestrian zebra markings	Y	
Signals installed	Y	
Simplified two-phase signals (Right turns across the busway prohibited or squareabout designs)		Y
Concrete surfacing of busway on all approaches	Y	
Signals installed and programmed for new signal cycle	Y	
Accessible ramps installed on all corners and refuge islands	Y	
Operations and management:		
SPV/BRT cell formed and functioning		Y
Standard Operating Procedures	Y	
Drivers training	Y	
Traffic wardens training	Y	
Security guards training	Y	
Fare collector (off board or on board) training	Y	
PIS testing- buses and BRT stations	Y	
Operations schedule	Y	
Route rationalisation		Y
Headway of any BRT route on the corridor is less than 20 min as per service plan		Y
Integrated ticket with easy transfers		Y
System logo is put on all the BRT buses	Y	
Appointment/identification of field officers to monitor–bus and bus station cleanliness, no breakdowns, maintenance	Y	
Central control centre installation and testing	Y	
Bus cleaning and maintenance facilities	Y	
GPS testing and verification	Y	
Station door operations testing and verification	Y	
Station UPS testing and verification	Y	
Bus lane enforcement notification (traffic police)	Y	
Terminal supervisors and starters	Y	
Communications:		
Route changes information design	Y	
Route changes information publication/outreach	Y	
System website		Y
Communications officer		Y
Grievance redressal system	Y	
ID cards for system staff	Y	

16. CARE TO BE TAKEN WHILE IMPLEMENTING BRT

It is desirable to take care of following factors while planning, constructing and operating BRT system:

16.1 Network Length

Some cities construct small segment(s) of dedicated BRT corridor(s) that may not give desirable results. Short (and sometimes disconnected) corridors benefit limited number of commuters and create a negative image of the system and about the concept of BRT itself, and run the risk of being considered a failure. When planning a BRT system, a reasonable network should be identified. While implementation can be phases, systems should be expanded in a time bound manner to benefit a substantial number of people.

16.2 Dedicated High Quality Fleet

For a BRT to be high quality system that serves the public well and wins their confidence, it should have an attractive fleet of buses. The BRT system should be projected as a “Metro on the Road”, with buses that have quality similar to metro rail coaches.

16.3 BRT Lane and not a Bus Lane

BRT is the coming together of multiple design and operational elements to create a seamless user experience and enhance efficiency. For example, bus floor height should match the station floor height to facilitate step-less boarding and alighting. Some cities allow buses of all types into the BRT corridor—including various types of city buses, intercity buses, school buses, and company buses. Such decisions have the effect of converting the BRT corridor to a mere bus lane. This significantly reduces the efficiency of the system.

To maintain efficiency, provide seamless customer experience, and create and maintain a strong brand amongst public, BRT must not be diluted. Only specially designed buses that belong to the system must be allowed on the corridor. Attempt must be made to rationalise city bus routes to reduce or eliminate overlap with BRT services.

16.4 BRT Station Location

BRT station locations on the corridor are very critical. While proximity to passenger demand location is important, it should be noted that the stations should not be placed right at the intersection. It has been observed that the systems with stations located right at the intersection, don’t provide sufficient queueing space for buses. Moreover, they occupy lanes which could be added for queuing of mixed traffic, thereby maximising the throughput of the intersection. Poor intersection throughput may result in annoyance about BRT in the minds of motor vehicle users.

16.5 Median Alignment of BRT Lanes

Medians are the most appropriate location for BRT lanes since they provide rapid and uninterrupted movement for buses. Kerb side bus lanes are frequently obstructed by parked or stopped vehicles, vehicles turning left into side streets or properties, as well as other slower moving traffic and are therefore inappropriate for BRT. Bus passengers routinely cross streets to access bus stops that happen to be on the other side of the street. Rather than crossing the entire street width around half the time, a BRT passenger has to cross only half the street width at all times. Hence, a BRT passenger has to cross no more than a passenger of a regular city bus service. Further, frequent and safe street crossing opportunities are a defining feature of a good urban road. BRT stations- integrated with signals provide a safe opportunity to cross the street to reach the stations in the median.

16.6 Intersection Design

Intersections are complex and can easily become bottlenecks in many Indian cities. Very long traffic queues, running into hundreds of meters, becomes a routine affair. In fact, some poor BRT systems have signal cycles which areas long as 8 to 12 minutes. Motor vehicles often have to wait for even up to three such long cycles before they are able to clear the intersection, resulting in undue delay to both personalised vehicles and buses.

16.7 Overlap with Rail-Based Mass Transit Systems

It is essential to analyse the desire lines of the commuters in situations where a BRT line might overlap an existing or proposed Metro or other forms of urban rail lines. While rationalising services is a laudable effort to improve utilisation of resources, one must not forget the primary goal of maximising public transport passenger convenience. In cases where the overlap between the rail line and specific BRT routes are small, and removing the BRT route would cause one or more needless transfer that might potentially push the passengers away from public transport altogether. It is advisable to allow an overlap of systems. However, all attempts must be made to integrate such systems to create seamless connectivity and maximise customer options.

16.8 Bus Operations Monitoring

Due to lack of monitoring the operations, there may be bus bunching at stations and at intersections, resulting in a reduction of speed, crowding at stations, and overall degradation of efficiency. Poor bus maintenance results in breakdowns during operations. GPS-enabled BRT buses should be monitored and controlled using two-way communication system to reduce bunching and for maintaining desired headways.

16.9 BRT Fleet Expansion

Some systems fail to augment the fleet size to cope with the increase in demand and if the demand stagnates, it may lead to promoting greater use of personal motor vehicles that eventually demand the removal of BRT to get them more road space. Therefore, cities must ensure that the BRT bus fleet is continuously augmented to not only match the existing demand but also have additional capacity to attract new users.

16.10 Interdepartmental Coordination

Any mass transit system needs close involvement of various government organisations in the city/region. Typically, the BRT systems in India need involvement of municipal corporations, traffic police, regional transport office, sometimes state or National highways departments and the existing bus operating company or the department. Cities that lack interdepartmental coordination end up with poor system performance because of issues like two city bus systems (regular and BRT) on the same corridor that confuse the passengers and results in unnecessary competition, or traffic police allowing private vehicles to use the bus lane during peak hours, or lane segregation is missing on part of the corridor due to land encroachment issues etc. Cities must bring together all stakeholders, especially different public offices, to ensure their support and ownership of the system.

16.11 Supporting Infrastructure

A good BRT system needs supporting infrastructure like passenger terminals, depot and maintenance areas. Lack of passenger transfer stations and waiting areas result in discomfort to passengers, increases operations and maintenance cost. A BRT system must have supporting infrastructure that is typically provided to rail based MRT systems.

16.12 Fund Allocation

Public transport systems, whether BRT or otherwise, often need subsidy from the government to provide affordable mobility options to citizens. However, many Indian BRT systems find it very difficult to get necessary funding to meet the operational losses or augment fleet, whether it be from urban local bodies or their state government. At the same time, these cities manage to spend large sums of money on short term options like vehicular grade separators and construction of off street parking blocks that only facilitate the use of personal motor vehicles that cause many negative externalities such as traffic congestion, pollution, and unsafe road conditions. Cities must financially support public transport systems, especially bus-based systems such as BRT that can service the needs of the majority.

16.13 Skilled Manpower

BRT systems need regular planning and monitoring. They need competent professionals from the fields of transport planning, finance, law, and human resource management. They also need trained drivers and other staff for functions such as ticketing and security to providing quality service to passengers. The establishment of a special purpose vehicle or a special department to plan, manage, and monitor the operations of BRT, with sufficient skilled manpower, is essential. To maintain high standards of quality of service, drivers and other operations staff must be trained and skilled in their respective trade and function.

17. COMPARISON OF VARIOUS SYSTEMS ACROSS PARAMETERS

Quantitative Parameters	Bogota	Mexico city	Ahmedabad	Pune- Pimpri Chinchwad	Delhi (before 2015)
System name	Transmilenio	Metrobus	Janmarg	Rainbow	Delhi BRT
Number of corridors in operation in 2017	11	4	13	4	0
Total length of dedicated bus way	105 km	81.5 km	88.8 km	36 km	5.6 km (rather small)
Average Distance between stations	790 m	600 m	600 m	500 m	500-800 m
Station platform height	1000 mm	1000 mm	900 mm	880 mm	380 mm
Number of BRT stations	144	115	153	56	9
stations with functioning passing lanes	all	0	0	0	0
Number of BRT terminals	7	6	16	2	NA
Number of BRT depots	7	NA	4	4	NA
location of busway lanes	Centre of roadway	Centre of roadway	Centre of roadway	Centre of roadway	Centre of roadway
Operational mode	Closed system with trunk and feeder configuration	Closed system with trunk only operations. Integrated with Metro rail	Trunk and feeder service with some hybrid sections	Hybrid services. BRT buses operate with service extensions. Non-BRT buses are not allowed on the corridor.	Open. All types of buses could access the BRT corridor (has been dismantled now)
BRT fleet	1215	301	250	260	NA
Location of bus doorways	One side	One side	Both sides	Both sides	One side
BRT vehicle length	18 & 24.5 m	12,18 & 25 m	12 m	12 m	13 m
BRT vehicle Fuel	Diesel	Diesel	Diesel	CNG	CNG
Number of BRT routes	102	18	13	42	57
Peak throughput (passengers/hr/ direction)	37,700 pphpd (Calle 76)	7,550 pphpd	2,300 pphpd (Maninagar to RTO circle)	3,600 pphpd (Sangavikiwale)	6,500 pphpd (Ambedkar Nagar to Moolchand)
Peak city centre buses/hr/ direction	312 buses/hr	56 buses/hr	54 buses/hr (Maninagar to RTO circle)	60 buses/hr (Nagar road)	120 buses/hr
Maximum peak hour speed	30 kmph	NA	24 kmph	27 kmph (Sangavikiwale)	18 kmph
Average bus occupancy (peak hr & direction & point)	132 (articulated buses)	135 (articulated buses)	48 (standard buses)	60 (standard buses)	NA
Fare type(flat, zonal, distance-based, other)	Flat	Flat	Distance-Based	Distance-Based	Distance-Based
Type of Fare collection/ verification technology	Smart card	Smart card	Smart fare collection at stations with real-time updates to central control centre. Paper ticket also issued from electronic ticketing at stations.	Paper tickets issued from electronic ticketing machines.	Paper ticket
Infrastructure cost/km	NA	NA	~11.7Cr/km	~13Cr/km	~14.89 Cr/km
BRT management agency	TransMilenio SA	Metrobus	Ahmedabad Janmarg Ltd.	PMPML	DIMTS, DTC and STA

Above details are from various sources. For more details about Delhi and Ahmedabad BRT, readers may refer to research papers mentioned in the list of references.

REFERENCES

- CRRI Report (2012) Evaluating Bus Rapid Transit (BRT) Corridor Performance from Ambedkar Nagar to Moolchand, Delhi
- Embarq. (2015). Designing Safer BRT: Experience from BRT safety audits in India.
- Embarq. (2015). Traffic Safety on Bus Priority Systems. Retrieved from http://www.wricities.org/research/publication/traffic-safety-bus-priority-systems
- Institute for Transportation and Development Policy. (2007). The BRT Planning Guide. Retrieved from https://www.itdp.org/the-brt-planning-guide/
- Institute for Transportation and Development Policy. (2014). The BRT Standard. Retrieved from https://www.itdp.org/the-brt-standard/
- Institute of Urban Transport, India. (2011). BRTS Evaluation and Design Tool (BEAD), User Manual. Retrieved from http://www.iutindia.org/downloads/Documents.aspx.
- Kathuria, A., Parida, M., Sekhar, R., Pathak, M., Examining Bus Lost Time Dynamics for a Bus Rapid Transit Station. Journal of Public Transportation, 2016, 19(2), 172-186.
- Kathuria, A. (2017) Operational Analysis of Bus Rapid Transit System, Doctoral Dissertations, Indian Institute of Technology Roorkee, Roorkee C.
- Shakti Sustainable Energy Foundation. Samarthyam. (2014). Universal Accessibility Guidelines for Pedestrian, Non-motorized Vehicle and Public Transport Infrastructure
- Samarthyam. (2013). Accessible Transport Toolkit
- Transportation Research Board. 2013. Transit Capacity and Quality of Service Manual, 3rd Edition. Washington, D.C.
- Gautam Raj Godavarthi; Ravi Sekhar Chalumuri; and Senathipathi Velmurugun, (2014) Measuring the Performance of Bus Rapid-Transit Corridors Based on Volume by Capacity Ratio, Journal of Transportation Engineering, American Society of Civil Engineering Vol. 140(10)
- EMBARQ, the World Resources Institute Center for Sustainable Transportation (2009), Delhi bus corridor: an evaluation.
- Science Direct, Procedia - Social and Behavioral Sciences 104 (2013) 825 – 834, Micro simulation Based Performance Evaluation of Delhi Bus Rapid Transit Corridor retrieved from http://www.sciencedirect.com/science/article/pii/S1877042813045680 http://www.crridom.gov.in/content/evaluating-bus-rapid-transit-brt-corridor-performance-amebedkar-nagar-mool-chand
- Far East BRT, BRT Data Portal (http://www.brtdata.net)

(The Official amendments to this document would be published by the IRC in its periodical, 'Indian Highways' which shall be considered as effective and as part of the Code/Guidelines/Manual, etc. from the date specified therein)