HIGH CAPACITY BUS SYSTEMS

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INTRODUCTION

With rapid urbanisation, the pressure on transportation systems has increased in most cities in India. The inadequate transport system of cities, accompanied by lack of comprehensive urban transport management strategies is promoting the use of private individual transport. As an example, Delhi alone has experienced a nine-fold increase in its motor vehicle population over the last three decades, with public transport contributing little to this increase.

Significant environmental, safety and health implications are associated with high traffic density and inefficiently designed urban transport systems. Most cities continue to face the problems of environment pollution, slower vehicular speeds, and traffic congestion accompanied by unacceptable accident rates. As a result, urban India encounters acute transport crisis and deteriorating air environment.

This situation calls for innovative, cost effective, safe and reliable transport strategies. Modern High Capacity Bus Systems (HCBS) integrated with information and communication technologies provide such an option for decongesting and improving urban transport situations. In most cities, buses are still the most widely used mode of conveyance and will continue to remain so. Therefore, it is crucial that urban planners start looking at innovative ways by which the efficiency of the bus transport can be improved to cater o the growing urban population. Preferential right of way for buses along with priority for pedestrians and cyclists, intelligent transport systems, cleaner fuels and vehicle technologies could be the way forward for meeting the transport needs of our cities in the future.

HCBS is a term used for bus transportation systems that use available space on arterial roads of cities with dedicated bus ways. These systems utilize modern technologies for optimising flow, passenger movement, ticketing, bus scheduling, etc. The efficiency of the system and high capacity of passengers transported depends on the system as whole and not necessarily on the size of buses, though when necessary articulated buses could be used with ease. HCBS is a high-quality customer oriented transit that delivers efficient, low cost and fast urban mobility. These systems can be implemented at a fraction of the cost of rapid transit systems available earlier. Such systems have the following characteristics: segregated busways, rapid boarding and alighting, efficient fare collection, comfortable and efficient shelters and stations, use of clean bus technologies not limited to any particular type, and flexibility in routing. Such systems increase the capacity of existing bus systems significantly and can be implemented in relatively short time spans of 1-2 years.

In this chapter we give the background of HCBS, international experience, relevance to Delhi and estimates of costs and benefits.

BACKGROUND ON HCBS

HCBS systems have been introduced in a large number of cities in the developing world, and even advanced economies are now following this example.

Some of the cities where such systems have been introduced or are in an advanced stage of implementation are listed below:

1. Latin America:
   Belo Horizonte, Bogota, Campinas, Curitiba, Goiania, Lima, Porto Alegre, Quito, Recife, Sao Paulo

2. Asia:
   Akita, Fukuoka, Gifu, Kanazuwa, Kunming, Miyazaki, Nagaoka, Nagoya, Nigata, Taipeh.

3. Oceanía:
   Adelaide, Brisbane.

5. North America:
   Honolulu, Los Angeles, Miami, Ottawa, Pittsburg, Vancouver.

In addition, the following cities are at planning or construction stages:

1. Latin America:
   Barranquilla, Bogota (expansion), Cartagena, Cuenca, Guatemala City, Guayaquil, Lima, Mexico City, Panama City, Pereira, Quito (expansion), San Juan, San Salvador.

2. Asia:
   Bangalore, Surabaya.

4. Oceanía:
   Auckland, Perth, Sydney.

5. North America:
   Albany, Alameda and Contra Costa, Boston, Charlotte, Chicago, Cleveland, Dulles Corridor, Eugene, Hartford, Las Vegas, Louisville, Montomery County, San Francisco, Seattle, Toronto

Basically, HCBS can be defined as a fully integrated, bus-based “rapid” transit system typically utilizing highly flexible service and advanced technologies to improve customer convenience and reduce delays. It combines most of the qualities of light rail transit with the flexibility and lower operating, maintenance, and capital cost of buses. HCBS vehicles can operate on exclusive travel ways, high occupancy vehicle (HOV) lanes, expressways, or ordinary roadways in almost any dense urban environment. In addition, HCBS can combine intelligent transportation systems (ITS) technology; traffic signal priority; rapid, limited stop service; clean, quiet, and aesthetically pleasing vehicles; enhanced shelters and stops; rapid and convenient fare collection; and facilitated integration with existing and future land-use policy. The following features typically characterize a HCBS system:

- Exclusive travel ways
- Modern stations
- Modern buses

- Rapid service
- Automated fare collection
- ITS technologies
- Lower costs

It is not necessary that all of the above systems be available at the same time. They can be incorporated in phases or as per need on different sections.

Exclusive travel ways

A "travel way" is the path along which a HCBS vehicle operates; the use of an exclusive travel way is what distinguishes HCBS from standard local transit service and helps give it a higher-than-standard-bus speed, reliability, and identity. Some of the types of travel ways that can be used include exclusive transit way, HOV lanes, dedicated transit lanes, mixed traffic, contraflow lanes, and queue jumper lanes at signalized intersections. In some HCBS applications, the travel way is color-coded or has special pavement markings to enhance its distinctiveness. These exclusive lanes can be on the left (curbside) lane or on in the centre of the right of way. Extensive experience has been accumulated around the world in the allocation of these locations and the decisions have to be based on land use patterns, right of way available and density of bus traffic. In some locations, emergency vehicles and high capacity vehicles like taxis are also allowed on these lanes.

Modern stations

HCBS system stations can range from standard shelters to large transit centers, depending on the character and/or the density of the community in which the HCBS operates. HCBS stations often are tied to major activity centers such as malls, business parks, and downtowns, and even can be located "off-line" from the travel way. Typically, station design further promotes fast, efficient HCBS service by reducing vehicle dwell time. One of the major ways that this is accomplished is by speeding up the passenger boarding and alighting process by using raised platforms for no-step passenger movement on and off the vehicles and/or buy the use of low-floor buses. HCBS stations also utilize signage and graphics to differentiate and make them stand out from standard bus stops. In addition, HCBS stations also can include real-time passenger information displays and provide opportunities for other customer services.

Modern buses

In the early stages it may not be absolutely necessary to provide all buses that are new, but the full capacity of the system can be achieved only if the bus design I integrated with the bus stop and communication systems. Some of the critical issues are outlined below.

Low-Floor Vehicles

HCBS systems typically use low floor buses to reduce dwell time, make travel more convenient and make possible use by disabled persons easier. For diabled persons, access to the vehicle can either be at raised platforms (providing *level boarding*) or using an on-vehicle ramp which flips down to bridge the gap between the step and the curb.

Number and Width of Doors

HCBS require buses with more and wider doors to reduce dwell time. A clear width of 820 mm is desirable for easy access by persons in mobility aids. Three doors may be there in a 12m bus, which increase passenger-handling capability at stops or stations by 50 percent.

Internal Circulation

HCBS systems should make movement of passengers within the bus smoother and faster. Wider aisles and higher standing capacity can increase overall capacity of the bus and also improve movement inside the bus. However, these designs require careful ergonomic design of seats, aisles and grab-handles and poles.

Noise and Emissions

The success of the HCBS system also depends on its public image and environmental issues. Therefore, the HCBS buses must be less polluting and quieter in operation.

Safety

Special care needs to be given to make these buses safer both for occupants and for other road users around them. In future these items could include IT systems for hazard detection and roadway information systems.

Propulsion

All modes of propulsion – diesel, CNG, LPG, hydrogen cell, electric trolley buses (ETB) – can be used in HCBS. ETBs are proven technology, have no emissions from the tailpipe, and are the quietest transit mode of all, but they are costlier than other buses.

Rapid service

HCBS provides a wide array of options for integrating the various systems. High-speed express buses can operate on the same route as regular buses. To enable this, overtaking facilities have to provided only at those stops which are to be skipped at the express buses. Buses entering the HCBS route from other routes can also provide faster travel on this section.

Automated fare collection

In most bus systems, fare collection slows down operations. The new system should incorporate use of smart cards, ticketing at bus stops, wider use of weekly/monthly passes, etc.

ITS technologies

Providing information to customers is a crucial part of providing reliable, efficient, and convenient BRT service. A customer arriving at a stop or station should be able to readily find information about routes, the hours and frequency of service, a system map, and other pertinent information. Although this type of static information is useful, real-time information is even more valuable to customers. Such information requires the use of ITS technologies such as an automatic vehicle location (AVL) system to track the exact location of vehicles in the system. The information from the

AVL system then can be converted into vehicle arrival times that can, in turn, be displayed in real time to customers at stations, kiosks, Internet/radio/television, or transmitted over information networks. Customer information inside the bus can also provide real time data regarding present location, next stops and estimated time to destinations.

Another important component of HCBS is *Traffic Signal Priority,* which is simply the idea of giving special treatment to transit vehicles at signalised intersections. Since transit vehicles can hold many people, giving priority to transit can potentially increase the person throughput of an intersection. There are many different options for signal priority logic. Real-time, *adaptive* systems can incorporate information on traffic flow, flow coordination, bus schedule adherence, and prior bus arrival times. These systems are now relatively inexpensive and can be incorporated both in the bus and traffic signals.

ISSUES FOR DELHI

Various types of bus operations are possible including local services with frequent stops, express service with limited stops, peak period services, charter services, feeder services and shuttle services. The standard of service is usually perceived in terms of reliability, frequency, journey time, and quality of ride, which may vary from air-conditioned comfort to extreme crush loading conditions.

Other than the low cost compared to rail based transit options, a major advantage of bus transit is its flexibility in meeting changes in the shape of the city development and in changes in demand in terms of quantity and quality. If necessary, existing bus routes can be modified almost overnight at virtually no cost. Expanded or new services can be introduced quickly and at relatively low initial cost.

Electric trolleybus systems, however, lack the flexibility of conventional bus transit because they are constrained by their overhead power transmission system, and involve considerably higher costs, although substantially lower than rail based system. The trolleybuses can be considered as low-cost non-polluting solution for high volume polluted corridors. Use of ETBs does not preclude other buses form using the same corridor as the road surface is not altered.

Physical Characteristics of a Bus System

A bus based transit system can operate under three environments:

a) *Under mixed traffic:* In mixed traffic conditions, buses share the same road space with other vehicles. Their speed, capacity, reliability and quality of service is largely influenced by the presence of other vehicles, such as cars, scooters/ motorcycles, bicycles and pedestrian. In Delhi, buses operate under mixed traffic conditions and get the same treatment as other modes. The major constraint in mixed traffic is the friction between non-motorised traffic and buses in the left lane. <u>Unless slow traffic is given a separate physically segregated lane it is impossible to improve bus operation in Delhi</u>.

Transit systems using standard-size buses, each with a capacity of about 80 passengers, are able to carry up to 10,000 passengers per hour per lane in mixed traffic. Systems using larger buses with a capacity of 120 or more, operating in the same conditions, can carry up to 15,000 passengers per hour. Journey speeds (including stops) in mixed traffic conditions is likely to be in the region of 12 km/h. Where buses can use several lanes in the same street, much greater passenger volumes can be accommodated. Under these circumstances the limiting factors are likely to be the amount of stopping space for boarding and alighting, and terminal facilities. Although journey speeds are low, particularly in congested areas, volumes of between 25,000 and 30,000 bus passengers per hour in one direction occur on main roads in a number of cities throughout the world. However, this has reached its limits in Delhi, and causes other problems like congestion for all road users and high level of accidents.

b) *Bus lane:* Bus lanes are reserved spaces allocating priority to buses over other forms of transportation through the use of painted lines and signs. Private vehicles may use the lanes during only non-peak hours. However, due to lack of hard barriers, the bus lanes are susceptible to private motor and non-motorised traffic. This experiment has not been successful in Delhi.

c) *Exclusive Busways*: These are bus lanes physically separating buses from other traffic flow through the use of median strips and barriers, with grade separation or priority at intersections. In general, off-line stations with terminals are provided with multiple platforms for boarding and alighting. Busways are now considered to be the most efficient form of a mass transportation bus system. Buses do not suffer from interference from private motor vehicles and there is no requirement for police control as bus priority is guaranteed through physical segregation. As a result of this, higher speeds are able to be achieved. Bus lanes can largely improve the regularity by eliminating 70% of the factors that cause delays. Higher frequencies can be achieved for lower operational costs.

With off-line stations and terminals providing multiple boarding platforms, volumes in excess of 30,000 passengers per hour per lane, and journey speeds between 15-30 km, may be reached. Busways with the potential for achieving these levels of performance exist in several cities. Yet, even without completely exclusive conditions, the Sao Paulo busways carry more than 27,000 passengers per hour in a single lane at journey speeds of 19 km/h. Buses operate in convoys and stop opposite a series of designated bus stops in a predetermined sequence so that the passengers can embark or disembark from several buses simultaneously. Comparatively low-cost modifications to the system could boost capacity significantly. Clearly, where reserved bus lanes and exclusive busways are established in several streets in the same bus corridor, the capacity of the system to move passengers along the corridor can be substantially increased. Between, the two extremes of mixed traffic and exclusive busways are many variations and the capacities are proportional to the degree of reservation.

Since buses using busways or bus lanes can disperse to several terminals in downtown areas, very high concentration of passengers in buses can be avoided. Similarly, outbound buses are able to fan out into suburban areas after leaving busways or bus lanes. In other words, passengers can be taken close to their destinations at both ends of these high capacity facilities. Bus systems also have the added advantage of being flexible and routes can be changed when the city-characteristics change. On the other hand MRTS system get fixed for ever.

Road infrastructure

Delhi has an extensive road network with a total length of 26, 582 km (year 1996–97) of which approximately 1148 km has a right-of-way 30 m and above. Nearly 500 km of these roads already exist, and the remaining 852 km is proposed in new developments. In general, most arterials are six lane divided roads. Average speeds have been reducing over the years. Peak hour traffic on arterial roads crawls through bottlenecks at major intersections. However, at non-peak hours, mid-block speeds tend to be much higher, ranging from 50 to 90 km/h for buses and private motorized vehicles, respectively. This leads to higher fatality rates on one hand and on the other, longer waiting periods at junctions. It seems that the problem lies with the poor management of the corridor traffic flow mixing high density of buses with other modes, resulting in increased levels of congestion. The traffic system does not meet the requirements of pedestrians, bicyclists and bus systems.

Delhi does not lack in availability of infrastructure in terms of space and length. However, the complexity arises due to the wide variety of vehicle types including humans, animal-drawn vehicles and bicycles that all share the same road space. With the available right of way on arterial corridors in Delhi, <u>a much better level of service and higher throughput can be provided only if the road space available can be used by all vehicles much more efficiently</u>. At present, due to lack of dedicated facilities, bicyclists have to interact with fast moving motorized traffic. Service roads, if present, are not maintained well. Footpaths are either not present or poorly maintained. The road network does not have any facilities for slow moving traffic (bicycles and rickshas), nor are there any dedicated facilities for buses, except sometimes a covered shed for bus stops.

Sustainable transportation options rely heavily on promotion of public transport and non-motorized modes. However, the actual policies promoted do not recognize the conflicts inherent in some of the measures suggested. Investments in transport improvement plans continue to focus on projects that benefit car users, at the cost of environment friendly modes such as bus transport, bicylcists and pedestrians.

The "critical" element in city transport systems

Meeting the specific needs of the most vulnerable groups in the city becomes crucial for the efficient performance of all traffic. For low-income people commuting to work, walking, bicycling or affordable public transport are not a matter of choice but a necessity for survival. Therefore, whether the roads have any specific facilities for these modes or not, they continue to be used by them. Delhi traffic laws do not segregate bicycle traffic and enforcement of speed limits is minimal. Motor vehicles (MVs) and non-motorized vehicle (NMVs) have different densities at peak traffic hours at different locations in the city. The existing traffic characteristics, modal mix, location details, geometric design, landuse characteristics, and other operating characteristics present a unique situation where economic and travel demand compulsions have overwhelmed the official plans.

On the two and three lane roads, bicycles primarily use the outermost lane on the left, i.e. curb side lane, and MVs do not use the left most lanes even at low bicycle densities. Bicyclists use the middle lanes only when they have to turn right. A study of fourteen locations in Delhi shows that maximum mixing of NMVs and MVs occurs at the bus stops.[1,2] Their interaction with other MVs is minimal at other locations. On three lane roads, the MV flow rates are close to or less than 4000 passenger car units per hour. This is much less than the expected capacity of three lane roads. The flow for these urban localities can be taken as 2000 passenger car units per hour per lane (Indian Road Congress). Though the peak volumes are not exceeding saturation capacities, we find the average speed remains in the range of 14–39 km/h. This shows that the left most lane is only partially used. However, if a space was exclusively available for bicyclists, throughput would increase by reducing friction with buses. Though de facto segregation takes place on three lane roads, an unacceptable danger exists to bicyclists because of impact with MVs. At three-lane locations, it is a waste of resources not to provide a separate bicycle lane because bicycles, irrespective of bicycle density, occupy one whole MV lane.

Since bicycles and other non-motorized vehicles use the left side of the road, buses are unable to use the designated bus lanes and are forced to stop in the middle lane at bus stops. This disrupts the smooth flow of traffic in all lanes and makes bicycling more hazardous. Motorized traffic does not use the curbside lane even when bicycle densities are low. Providing a separate bicycle track would make more space available for motorized modes and bicycling less hazardous.

Therefore, the critical element on Delhi roads that influences the efficiency of all motorised modes is the presence of non-motorised traffic. A pre-condition for providing an efficient HCBS would be the provision of physically segregated lane for non-motorised traffic.

Roadside vendors and services for road users

Bicycles, pedestrians and bus traffic attract street vendors. Often people selling food, drinks and other articles, which are demanded by these road users, occupy the side roads and pedestrian paths. Vendors often locate themselves at places that are natural markets for them. A careful analysis of location of vendors, number of vendors at each location and type of services provided them shows the need of that environment, since they work under completely "free market" principles. If the services provided by them were not required at those locations, then they would have no incentive to continue staying there. Street vendors and hawkers serve the same function for pedestrians, bicyclists and bus users. As long as our urban roads are used by these modes, street vendors will remain inevitable and necessary. HCBS corridor designs would have to give due consideration to this issue.

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[1] Tiwari, G, Mohan, D and Fazio, J (1998). Conflict analysis in mixed traffic conditions. *Accd. Anal. Prev.* 30(2), 207–215.

[2] Tiwari, G., *et al* (1998). *Bicycle Master Plan for Delhi*. Final Report submitted to Transport Department, Delhi Government, TRIPP, Indian Institute of Technology, Delhi.

Principles for providing exclusive bus and non-motorised lanes

HCBS systems with exclusive lanes would require at least 45 m right of way on roads to accommodate all road users on major arteries. Delhi has an extensive road infrastructure consisting of more than 450 km of roads with right of way greater than 45 m. The road network has to be designed from the perspective of the pedestrians, bicyclists and public transport vehicles. If the infrastructure designs do not meet the convenience of these users, they are forced to use facilities that are not designed for them, and all users are forced to operate under sub-optimal conditions. The guiding principle of the proposed design is to meet the needs of pedestrians and bicyclists in terms of convenience, safety, and comfort. This enables the existing space to be reorganized for giving priority to public transport – exclusive bus lanes, better designed bus shelters, spaces for vendors, and parking. These designs benefit all road users. A detailed study completed for the Government of Delhi shows how existing roads can be redesigned within the given right of way to provide for an exclusive lane for Buses and NMT modes.[3]

Detailed designs for road cross section and intersections have been prepared in Delhi on the basis of following criteria:

- Physically segregated bus and bicycle tracks on routes which have > 45 m ROW.
- Recommended lane width for buses 3.3 m (minimum).
- Recommended lane width for bicycles 2.5 m (minimum).
- Separate service lane and footpath.
- Recommended lane width on main carriageway for 2 car/two-wheeler lanes 3m (minimum) each.

- Intersection modification to include the following:

- Restrict free left turns
- Modify traffic signal cycle
- Roadside furniture to ensure safe bicycle movement and minimize interference from motorized-two wheelers

[3] Tiwari, G, Mohan D et al (1998). *Bicycle Master Plan for Delhi.* Final Report submitted to Transport Department, Delhi Government, TRIPP, Indian Institute of Technology, Delhi.

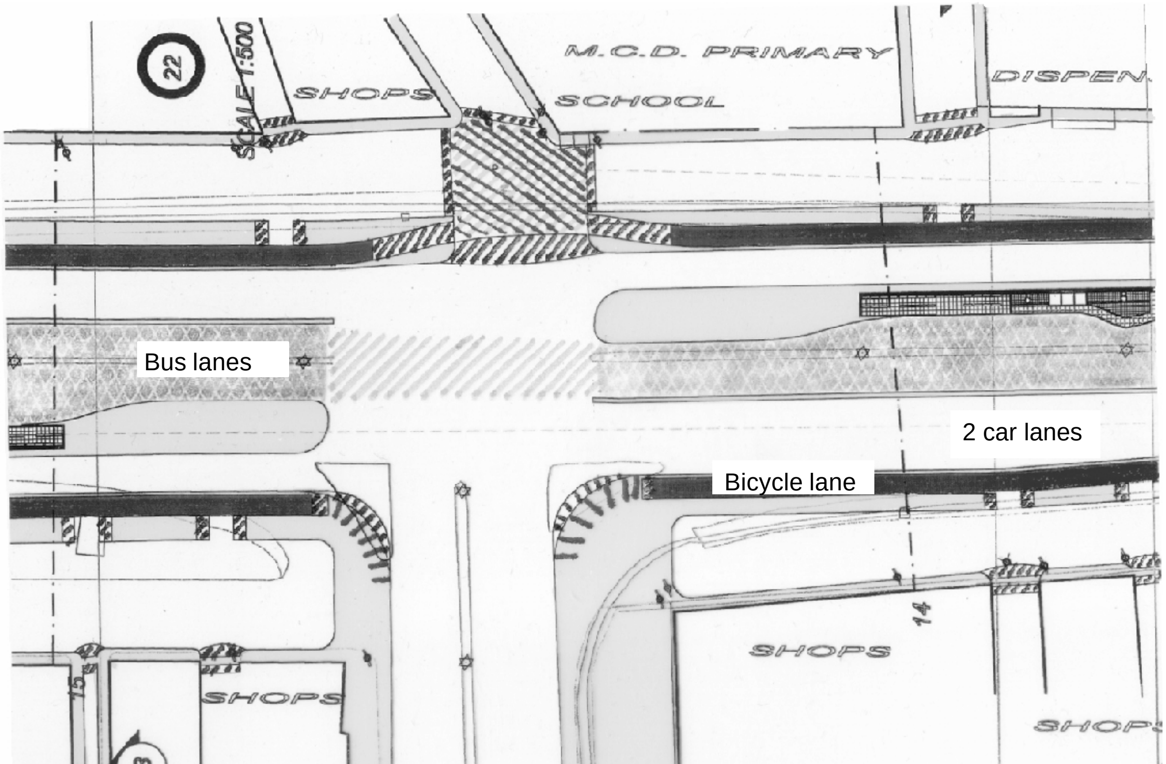

Figure 1. Arrangements for exclusive central bus lanes with non-motorised lanes on the curb-side.

Exclusive bus lanes can be provided either central two lanes physically segregated from rest of the traffic (Figure1) or as curbside bus lanes (Figure2). Table 1 lists criteria that should be adopted for choosing one of the two options. Figure 1 and 2 show detailed designs where two lanes of 3m each are proposed for the main carriageway in addition to the 3.3m wide central/curbside bus-lane. In the case of the central bus lane stretches the two 3.3m wide lanes combine to form a 6.6m wide undivided two way road. A 2.5 m wide cycle track is proposed throughout the length of the corridor running adjacent to the main carriageway (separated by a 0.4m wide divider on either side). A service lane is proposed between the cycle track and the peripheral footpaths all along the stretch with a minimum specified width of 3m. The flow, speed and direction of traffic is controlled by the design of the junctions and road surfaces. The design, of course, differs completely in the case of curbside bus lane and central bus lanes options.

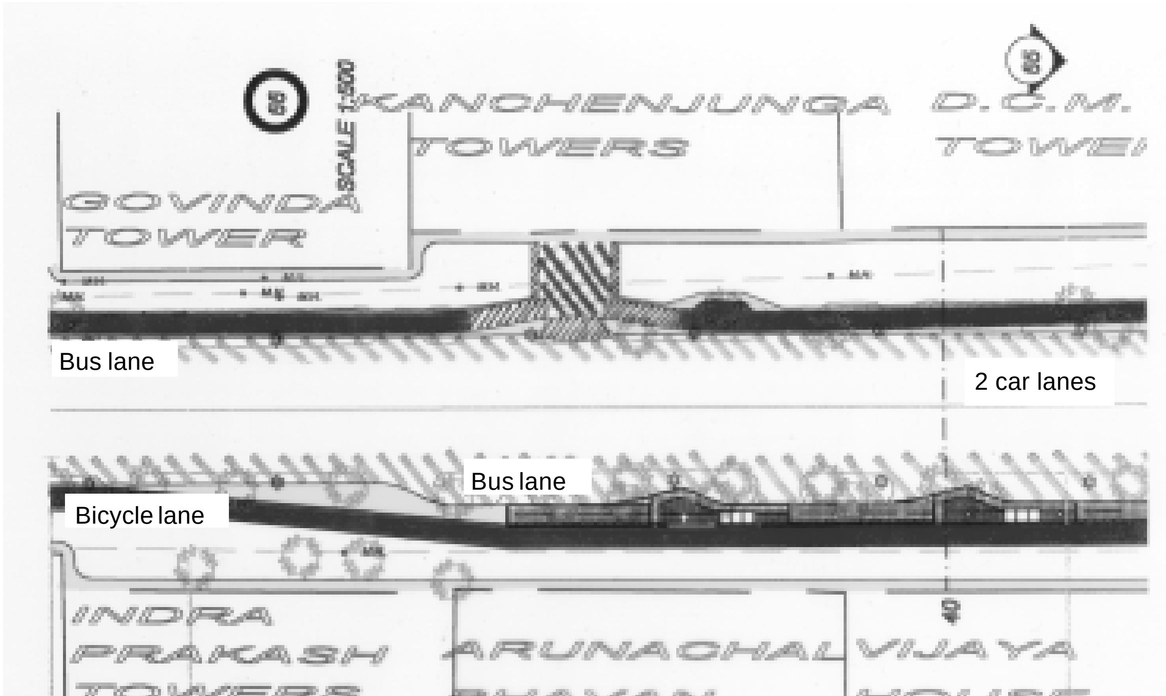

Figure 2. Arrangements for exclusive curbside bus lanes with non-motorised lanes also on the curb -side.

Intersection with Central Bus Lane:

Three lanes - straight, left-turning and right-turning are provided for the vehicles before the intersection and only one after it due to dispersal of traffic. However the single lane after the intersection is 4.5m. wide to allow for necessary leeway. The central bus stretch becomes 3-lane wide before the junction to allow for a left-turning lane. The bus lane before and after the junction are streamlined.

Intersection with Curb -side Bus Lane:

- An extra bay is provided for right turning traffic at junction.
- The bus lane before and after the junction are streamlined.

The minimum left turning radius according to which the curve of the intersection is plotted is (a) In case of buses not turning left : 7.5m with a sloped leeway of 1.5m for larger vehicles, (b) In case of buses turning left : 14m with a sloped leeway of 1.5m. This case specific designing allows for control of left-turning speeds thus ensuring safety and the speed transition between an arterial and residential road.

Bus stops have 2.8 m wide bus bay, 2.5 m wide bus stop and 1 m wide foot path. Hawkers have been provided space at the bus stop to minimize disturbance to the regular flow of pedestrian and cyclist traffic. The cycle track is diverted behind the bus stop in a gentle horizontal curve to reduce conflicts of cyclists with buses. This diverted path is raised to the footpath level and can be used by pedestrians too hence is widened from 2.5 m to 3 m.

Table1. Criteria for site specific choice between a central bus-lane layout and a curb -side bus -lane layout

Sl. No.	Central Bus Lane	Curb-Side Bus Lane
1.	**Excessive side-entries for vehicles into service lanes or individual plots.**	**Limited access to service lanes or widely spaced entry points into adjoining area.**
Rationale	The high volume of turning traffic interferes with the through movement of bus traffic if the bus uses the same curb-side lane as the turning vehicles.	
2.	**Closely placed traffic lights for vehicles.**	**Traffic lights at larger intervals.**
Rationale	Buses using the curb-side lane are forced to stop at every red signal with other vehicles reducing throughput and encouraging passengers to board and alight in unsafe areas.	
3.	**Low frequency of bus-stops**	**Higher Frequency of bus -stops**
Rationale	If the frequency of bus -stops is higher a central bus-lane will create too many pedestrian crossings defeating the its purpose while a curb-side bus lane will provide safer and more efficient bus -stops.	
4.	**Higher volume of two-wheeler and three-wheeler vehicles**	**Lower volume of two-wheeler and three-wheeler vehicles**
Rationale	High volumes of two -wheeler and three -wheeler vehicles interfere with the movement of buses in the curb -side lane especially at the bus-stops where buses often cannot approach the designated bus-bays due to the three -wheelers parked there and the two-wheelers trying to overtake from the left-side. Also, the difference in sizes of these vehicles sharing the curb -side lane makes the situation unsafe for the smaller vehicles.	
Eg.	**Arterials through heavy commercial landuse areas like Vikas Marg**	**Highways through large institutional areas like stretch of Ring Road in ITO area.**

Table2: Capacity Estimation in different scenario

Current				Exclusive Cycle track provided		Cycle track and HCBS			
Vehicles/h		Pers/h			Pers/h	Pers/h		Pers/h	Persons/h
		Bus=40	bus=80	Veh./h	bus=40	Bus=80	Veh./h	bus=40	bus=80
Cars	1404	1614.6	1614.6	1404	1614.6	1614.6	1404	1614.6	1614.6
MTW	1652	3634.4	3634.4	1652	3634.4	3634.4	1652	3634.4	3634.4
BUS	248	9920	19840	324	12960	25920	486	19440	38880
TSR	454	799.04	799.04	454	799.04	799.04	454	799.04	799.04
Cycle	338	354.9	354.9	338	354.9	354.9	4500	4725	4725
Total	4096	16322.9 4	26242.9 4	4172	19362.9 4	32322.94	8496	30213.04	49653.04
	~	**16000**	**26000**		**19000**	**32000**		**30000**	**49000**

1 Current mixed traffic is observed modal shares on Delhi streets.

2 Cycle track provided scenario includes exclusive cycle track for bicycles where max. 4500 bicycles can travel.
Space occupied by 338 bicycles in the mixed scenario becomes available for other vehicles. This is equialent to 338x1/2 = 169 cars = 169/2.2 = 76.8 buses. Since bicycles share the left Side lane with buses, therefore bicycle space is given to 76 additional buses.
However, the maximum capacity of this lane as per IRC standard is 1800 PCU or 1800/3.7= 486 buses. If we replace 338 bicycles with additional 76 buses then the existing level of congestion and speeds will be maintained.

3 Cycle track filled to capacity ~ 4500 bicycles,and left lane filled to capacity by buses ~ 486 buses Along with existing number of vehicles on the road gives the total capacity of the corridor.

Increased capacity

If a separate segregated lane is constructed for HCBS and bicycles, the curbside lane, which is currently used by bicyclists, becomes available to motorized traffic and buses. This relatively small investment in bicycle lanes can increase the road space for motorized traffic by 50% on three lane roads. Bicycle lanes also result in better space utilization. For instance a 3.5 m wide lane has a carrying capacity of 1800 cars per hour whereas it can carry 5400 bicycles per hour. Given the fact that there is not much space available to expand existing roads, the future mobility needs and projected trips can only be met by increasing the capacity of the existing road network. This can only be achieved by encouraging modes that are more efficient in terms of space utilization. Motorized vehicles benefit because of improved capacity of the road and improvement in speeds. Capacity estimations of a typical arterial road in Delhi show improvement in corridor capacity by 56–73% by provision of a high capacity bus lane and NMT lane.[4] A dedicated lane is provided for bicycles and the curbside lane is exclusively reserved for buses operating as HCBS. Other two lanes are used by all other motorized traffic. A dedicated 3 m wide bicycle lane can carry 4500 bicycles (maximum capacity of an urban lane is 1800 PCU ~ 4500 bicycles). Exclusive bicycle lane releases space on left most lane for buses. Therefore the maximum capacity of the left most lane is 1800 PCU ~ 486 buses (Table2). The results of the capacity estimation show that with the corridor capacity measured in terms of persons/ hour in existing patterns of mixed traffic, capacity can be improved by 19% by providing exclusive bicycle tracks. If the bus occupancy is taken as 80 persons/bus then 23% improvement in capacity can be realised by providing exclusive bicycle tracks. Not only does extra space on the main carriageway become available to other modes, the dedicated bicycle track also provides a higher capacity for bicyclists. Provision of exclusive bicycle track also provides an opportunity to develop left lane as an exclusive bus lane. Table 2 shows 88% improvement in capacity from 16000 (40 persons/bus) and 26000 (80 persons/bus) to 30000 persons and 49000 persons respectively. This is achieved by running 486 buses in the exclusive bus lane and 4500 cycles in the exclusive cycle lane. Table 3 shows capacity of the main carriageway(three lanes used by motorized vehicles). This does not include capacity provided by the cycle track. Corridor capacity improves by 19-23% by providing exclusive cycle track. However, utilizing the full capacity of the corridor i.e. provision of high capacity bus system in the left most lane can lead to capacity improvement by 56-73%.

Table3: Capacity in persons/h in three MV lanes (excluding bicycles)

	Bus=40		Bus=80	
	ExclusiveCycle Track	**Exclusive cycle track and HCBS**	**ExclusiveCycle Track**	**Exclusive cycle track and HCBS**
Car	1614.6	1614.6	1614.6	1614.6
MTW	3634.4	3634.4	3634.4	3634.4
Bus	12960	25920	19440	38880
TSR	799.04	799.04	799.04	799.04
TOTAL ~	**19000**	**32000**	**25000**	**45000**

Improved speeds

Improvement in speeds of motorized vehicles will be experienced until the corridor is full to capacity due to realization of induced demand. Major beneficiaries of speed improvement are buses and two wheelers because curbside lanes become available to them without interference from slow vehicles. Estimations of time savings experienced by bus commuters, car occupants and two wheeler commuters on a typical arterial corridor in Delhi show 48% reduction in time costs due to 50% improvement in bus speeds (from present 15 km/h to 30 km/h) and 30% improvement in car and two wheelers.[5]

Reduced congestion

Congestion has long been recognized as an environmental problem. Other than causing delay, it causes noise and fumes and increases health risks to road users and residents. Delhi as well as other Indian cities have invested in grade separated junctions and flyovers as one of the major congestion relief measure at an average cost of Rs. 100 million to 300 million for each intersection. However, detailed simulation of a major intersection in Delhi shows that re-planning the junction to include separate NMV lanes and bus priority lane can bring in 80% improvement over the present level of delays. Cost of this measure is 25 times less than the proposed grade-separated junction.

Increased safety

By creating segregated bicycle lanes and re-designing intersections, conflicts between motorized traffic and bicyclists can be reduced substantially leading to a sharp decrease in the number of accidents and fatalities for bicyclists and motorized two-wheelers. Safety benefits estimated for a typical arterial in Delhi show 46% reduction in accident costs. This is because a segregated facility reduces injury accidents by 40% and fatalities by 50%.[5]

INTERNATIONAL EVALUATIONS

1. A recent World Bank study makes the following comments on HCBS systems:[6]

- HCBS is clearly beneficial to the poor. Many of the poor use buses and busways create major accessibility benefits for them, particularly when they live in the outer city areas, and particularly with ‘open’ systems, or ‘trunk-and-feeder’ when there is through-ticketing. If ‘greener’ busways were developed, then the poor in particular would benefit from this through better health (they often spend long hours living, working or travelling in the street environment), but maybe at the expense of higher tariffs.
- Busways – where they are politically acceptable, busways should often be the first step in MRT system development, and for many cities they will remain the MRT system for the foreseeable future. We have seen that they can – in the

[5] Katarzyna, Tota (1999). *The role of non-motorized transport in sustainable urban transport systems: A preliminary analysis of costs and benefits of non-motorized and bus priority measures on Vikas Marg. Delhi*, prepared for TERI, Delhi.
[6] The World Bank. (2000). *World Bank Urban Transport Strategy Review – Mass Rapid Transit in Developing Countries.* Final Report, July 2000, Halcrow Fox in association with Traffic and Transport Consultants.

TABLE 4. Public Transport Options[6]

Characteristic	BUSWAY	LRT	METRO	SUBURBAN RAIL
Current Applications	Widespread in Latin America for 20+ years	Widespread in Europe Few in dev' g cities, none with 'high' ridership	Widespread, skewed to Europe and North America	Widespread, skewed to Europe and North America
Segregation	At-grade	At-grade	Mostly elevated/u' gd	At-grade
Space req' d	2-4 lanes from existing road	2-3 lanes from existing road	Elevated or u' gd, little impact on existing road	-
Flexibility	Flexible in both imp' n and op' s, robust operationally	Limited flexibility, risky in financial terms	Inflexible and risky in financial terms	Inflexible
Impact on Traffic	Depends on policy/design	Depends on policy/design	Reduces congestion somewhat	May increase congestion when frequencies high
PT Integration	Straightforward with bus operations. Problematic with paratransit	Often difficult	Often difficult	Usually existing
Initial Cost US$mn/km	1-5	10-30	15-30 at-grade 30-75 elevated 60-180 u' gd	-
Practical Capacity Pass/hr/direction	10-20,000	10-12,000? (no examples)	60,000+	30,000
Operating Speed Kph	17-20	20? (no examples)	30-40	40-50+

right environment, effect major improvements in accessibility, benefiting most of the city' s population, and particularly the poor. And they can achieve this quickly and incrementally as conditions and funding allow.

- o There are two forms of busway, ' open' in which buses join and leave, providing convenience for passengers who do not need to change bus; and ' trunk-and-feeder' which operates like light rail and requires interchange, often involving ' through-ticketing' and requiring more sophisticated institutional arrangements. The advantage is the additional operational control and capacity, which is created. Busway output depends greatly on road network configuration, junction spacing and stop spacing. If provision for bus overtaking at stops is provided, passenger throughputs of 20,000 pphpd have been demonstrated and schemes with 2-lanes each way are reported with even higher passenger flows.

2. An evaluation from the United States General Accounting Office on bus rapid transit sates that HCBS is generally more flexible than light rail:[7]

[7] *Mass Transit: Bus Rapid Transit Shows Promise* (2001). Washington, D.C.: United States General Accounting Office.

- Bus Rapid Transit can respond to changes in employment, land-use, and community patterns by increasing or decreasing capacity. Bus Rapid Transit routes can also be adjusted and rerouted over time to serve new developments and dispersed employment centers that may have resulted from urban sprawl. On the other hand, Light Rail lines are fixed and cannot easily change to adjust to new patterns of housing and employment. Although Bus Rapid Transit sometimes uses rail-style park-and-ride lots, Bus Rapid Transit routes can also collect riders in neighborhoods and then provide rapid long-distance service by entering a busway or HOV facility. Transit agencies have considerable flexibility to provide long distance service without requiring a transfer between vehicles. This is a significant benefit, because some research has shown that transit riders view transferring to be a significant disincentive to using mass transit. In contrast, Light Rail systems frequently require a transfer of some type— either from a bus or a private automobile. When Light Rail lines are introduced, transit agencies commonly reroute their bus systems to feed the rail line. This can have the effect of making overall bus operations less efficient when the highest-ridership bus route has been replaced by Light Rail; the short feeder bus routes can be relatively costly. Finally, bus-based systems' ability to operate both on and off a busway or bus lane provides Bus Rapid Transit the flexibility to respond to operating problems. For example, buses can pass disabled vehicles, while Light Rail trains can be delayed behind a stalled train or other vehicle on the tracks. Thus, the impact of a breakdown of a Bus Rapid Transit vehicle is limited, while a disabled Light Rail train may disrupt portions of the system.

- Bus Rapid Transit systems differ from Light Rail systems in that they provide greater flexibility in how they can be implemented and operated. In constructing a Bus Rapid Transit system, it is not necessary to include all the final elements before beginning operations; it is possible to phase in improvements over time. Improvements such as signal prioritization and low-floor buses, which improve capacity and bus speed, can be added incrementally. These incremental changes can have significant effects.

3. Robert Cervero, a professor of city and regional planning al the University of California at Berkeley whose recent research focuses on suburban transit issues says that "Certainly, buses are the most significant piece of the pie when it comes to transit. Far more people ride buses than rail. Plus our settlement patterns are more compatible with a more flexible transit mode. Too many American cities have it backwards. Instead of starting with compact development, they operate under the false assumption that, if you build rail lines, you will get people out of their cars." In Cervero's view, that won't happen until local officials make land-use decisions that support transit. His models are mostly foreign the German city of Essen, for instance, and Adelaide, Australia, both of which have guided busways. He points to Edmonton, Alberta, for its convenient transfer centers where "pulse scheduling" of local buses eliminates much of the waiting lime. U.S. examples include the Seattle suburb of Bellevue (where buses tie into a pedestrian path system); Portland, Oregon; Orange County, California: and the Norfolk area. Cervero makes the point that systems should be tailored to meet particular needs. That could mean flexible s rather than fixed service.

RECOMMENDATIONS

In light of the above observations and conclusions of the International Workshop on High Capacity Bus Systems sponsored by the Government of Delhi, IDFC and IIT Delhi, we can make the following remarks and recommendations:

Availability of Space:

Space available will have to be evaluated very carefully and the minimum amount of right-of-way necessary allocated for needs of personal motorised vehicles. Detailed guidelines for location of the dedicated bus way will have to be developed based on corridor conditions and international experience (experiment with the Curitiba/Bogota model). Space around the busways would have to be pedestrian friendly, with segregation of different road users (especially slow moving traffic), and integrated with the existing system.

Performance evaluation of Electric Trolley Busses (ETB) in Delhi.

Use of ETB will not be in competition with buses using other technologies. This is because ETBs can use the same corridor as other buses and have enough manoeuvrability. The technology to be used, integration with other modes, etc. must be evaluated carefully before deciding on the final specifications.

Project Planning and Institutional Arrangements

1. A special organisation would need to be established whose only job would be to carry out the high capacity bus system project. One possibility is the organisation of a SPV (Special Purpose Vehicle) – to be chaired by a high level official with strong leadership, adequate powers, and one who has a strong stake in the system. This arrangement would be essential for ensuring public-private partnership and coordination with all concerned agencies.
2. Such an organisation must be backed by strong political leader with appropriate powers and funding.
3. This special unit/organisation (or SPV) for the pilot project need not be the organisation which will become the operating agency of the future bus operating system for the whole city. However, the experience gained by this agency would provide the inputs for the structure for a future bus system. This special agency must involve interaction with the following stakeholders:

- Bus operators
- Media (for commuter awareness)
- NGO's for commuter feed back
- Government officials – road owning agency, Traffic Police, DDA, Local Municipal Bodies, etc.

Emissions and environment

- Strengthen the environmental control group at DTC to work toward achieving an emissions profile for all buses including those that are privately owned.
- Implement a program that includes the procurement of necessary equipment and monitoring of testing procedures worldwide.
- Strengthen the system to have a group of pollution control specialists, and specialists who can evaluate technologies.

- Employ more advanced monitoring techniques as these become available.
- Test for all major pollutants and fuel economy.
- Cost benefit analyses and cost effectiveness analysis should be undertaken before implementing any new policies
- Leave ambient testing to Delhi government
- Emission norms should be performance based and not technology based.

Safety

Unless commuting by bus is made safe from road accidents and crime for pedestrians and cyclists, it will be very difficult to attract more passengers as per capita incomes increase in our cities.

In the bus

- The code of practice, which has been approved, should be followed.
- Type approval of buses and bus bodies is needed in the future and standards and procedures need to be developed.
- Future plans should be developed for crash testing of buses for safety. Testing facilities exist at ARAI and VRDE, but these are not adequate and need to be upgraded and modernised.
- A system of third party inspectors needs to be established.
- For the near future, body builders should be accredited, and they should use approved designs and practices.
- Buses must have automatically closing doors and the bus should not be able to move with any doors open.
- Acceleration/deceleration standards need to be established.
- Computer software is available to test safety options – these should used to help design new safer buses.
- Arrangements should be made to eliminate crime on buses. Camera surveillance systems could be explored. Drivers should be able to report any incidents immediately so that culprits can be apprehended at the next stop.

At bus shelters

- Protection from the elements should be provided.
- The possibility of surveillance cameras at bus shelters can be explored.
- At major stops, have off-bus ticketing with the ticket seller also responsible for reporting any incidents.
- Presence of hawkers assists in maintaining a human presence around bus stops and this reduces possibilities of crimes. Bus stands need to be designed to provide facilities for hawkers, vendors and kiosks.
- Need a segregated traffic system to separate different traffic modes to avoid bunching and confusion at bus stops.
- Make sure area is clear just around bus stop.
- Emergency call box (police, ambulance) must be provided at all bus shelters.
- Transparent/open bus shelters should be encouraged to avoid hiding places.
- Bus shelters should have brighter lighting than rest of areas (lighted advertising can provide free light!) to prevent crime.

Safety on the streets around the bus route

- Make pedestrian safety central in the design of the bus system.

- Safety is compromised by multi mode competition. Enforcement to prevent non-buses from attempting to pick up passengers around bus stops.
- Pedestrian crosswalks should be well illuminated and marked. Arrangements should be made for safe crossing, especially for the elderly, children and the disabled. Such measures could include pedestrian refuges, traffic calming, etc.
- A bus stop catchment area is about 0.5km on all sides of stop. All of this area must be made pedestrian friendly.
- Safety audit of a 0.5km band around bus route should be undertaken routinely.
- Fixed objects in area should have crash protection.
- Traffic calming around bus stops – scientific design of sleeping policemen, etc. – speed breakers not enough.
- Overpasses, underpasses for pedestrians should be used only if absolutely necessary, but discouraged in general.
- All designs must conform with the provisions of theThe Disability Act – all public facilities must be wheelchair accessible.

Safety of other road users

- Dedicated bus lanes should be physically separated so that it is difficult for other vehicles to encroach in this space (with provision to remove broken-down buses).
- Dedicated bus lanes will function properly in India only if slow moving traffic like bicycles, ricks has and *thelas* also have their own segregated traffic lanes which go behind the bus stops. It is imperative that these designs be integrated in all bus route planning.
- Buses must be very conspicuous (bright colours, better brake lights, reflectors, etc.).
- Speed limits must be enforced by vehicle and infrastructure design and setting of realistic trip times.
- Pedestrian needs should be studied in detail – crosswalks should be provided where people actually cross.
- Future, buses should be "other-vehicle" friendly:
  - Bumpers should be compatible with other vehicles.
  - In particular, efforts should be initiated for developing a safety standard for fronts of buses in impacts with vulnerable road users.
  - Minimize driver distraction on the street

Institutional Mechanism for Safety

A professional Safety Department needs to be established. The Safety Department will have the following responsibilities:

- Routine safety audits of buses and areas around bus stations.
- Responsible for safety of whole system, including private buses.
- Develop and maintain a detailed data bank on all accidents, conduct analysis of associated factors, and develop appropriate countermeasures.
- All safety data should be publicly available for analysis by aother professionals.

ITS Related to Bus

<u>Short term application</u>

* For management:
  - o Real time management of fleet.
  - o Enforcement of discipline through use of cameras and other technologies.
  - o Training of personnel.
  - o Smart Cards to solve ticket-less travelling problems hence income increases for operator.
* For passengers
  - o Online information regarding routes, timings, etc. on the internet
  - o Single ticket journey
  - o Arrival information of buses at bus stands
  - o Route and stop information in buses

<u>Medium and Long Term</u>

* For management
  - o Network and scheduling for medium and long term planning.
  - o Command and control systems can be upgraded with new technology.
  - o Enables multi modal integration.
  - o Inventory management.
  - o Proper control in use of data and decision making processes.
  - o Financial accounting.
  - o Enforcement of rule violations.
  - o Fault diagnosis of bus fleet.
  - o Enables multimodal integration
  - o Technical and personnel management
  - o Signal coordination for bus priority at intersections
  - o Speed control and platoon management

- o For passengers

  - o Advanced traveller information system
  - o Information through internet, mobile phones, kiosks, bus terminals and important places
  - o Smart card application
  - o Real time information
  - o Multimodal journeys

Infrastructure

Use of public transport benefits all citizens of a city in terms of improved transport, reduced emissions per passenger transported and possibility of reducing deaths and injuries from traffic crashes. In view of this it is advisable for developing methods of raising finances from the citizens of a city for development of infrastructure. Innovative ways of taxation and investments need to be explored.

  - o In cities like Bogota, Curitiba, Quito, etc. the state/city has paid for the infrastructure.

- o Principles of implementing a graduated carbon or pollution tax on users of private vehicles based on amount of emissions can be explored.
- o Subsidised BOT was mentioned as a theoretical option. However, it was pointed out that except in one case in Brazil, all other attempts have failed.

Bus operation

* Private operators are the preferred option wherever possible. However, it was pointed out that these operators must be subject to the following:
  - o No competition among them for attracting passengers.
  - o There can be several large operators but using state infrastructure.
  - o The operators must be managed by a regulatory authority which decides routes, fare structure, quality of buses, etc.

* Full cost recovery (at system level) from fares if possible. However, public transport has to:
  - o Attract medium incomes (potential private vehicle users)
  - o Provide accessibility for all sections (including poor)
  - o In India, buses have to compete with affordability of motorised two-wheelers, which have relatively low costs of operation.
  - o Require the use of low polluting safe and modern buses which may be more expensive and whose operation may not be viable on fares alone in a low income country like India.

* Therefore, the following measures may be necessary:
  - o Government subsidy. It was mentioned that there are different options available for this. For example, it may be possible to subsidise the users directly rather than operators.
  - o Graduated services. Buses of different quality may be operated at different fares.
  - o Implementation of carbon, pollution or transportation tax.
  - o Maximise passenger capacity in buses
  - o Promotion of non-motorised transport to reduce pressure on public transport.

Fares

- o No fare competition among private operators
- o Operators paid according to bus km
- o Government corporation can collects fares (this system is followed by Transmilenio in Bogota)
- o Flat fares can be used because they are easy to administer. However, these may not be suitable for low income groups, especially for short journeys. These problems may be overcome by the use of smart cards and graduated fares.

CONCLUSIONS

1. High Capacity Bus Systems (HCBS) have emerged as the most favoured public transport systems around the world in the past decade. The technologies associated with HCBS are improving continuously with changes in IT and communication technologies. HCBS systems have been implemented, or are in the process of being implemented in more than 50 cities in every continent. The latest to join this group is Bangalore.

2. Use of ETB will not be in competition with buses using other technologies. This is because ETBs can use the same corridor as other buses and have enough manoeuvrability. The technology to be used, integration with other modes, etc. must be evaluated carefully before deciding on the final specifications. ETB may be introduced if necessary in corridors where atmospheric and noise pollution has to be brought to a minimum.

3. HCBS is considered to be the most cost effective mass transport system now. This is partly because the bus stops can be located close to the origins and destinations of commuters thus encouraging use and rider ship.

4. A dense HCBS is ideally suited for a relatively low-rise city. Very high capacity systems are more viable in high-rise environments.

5. HCBS routes can be adjusted and rerouted over time to serve new developments and dispersed employment centres that may result from urban sprawl. On the other hand, Light Rail lines are fixed and cannot easily change to adjust to new patterns of housing and employment.

6. Given the fact that there is not much space available to expand existing roads, the future mobility needs and projected trips can only be met by increasing the capacity of the existing road network. This can only be achieved by encouraging modes that are more efficient in terms of space utilization.

7. Unless slow traffic is given a separate physically segregated lane it is impossible to improve bus operation in Delhi. With the available right of way on arterial corridors in Delhi, a much better level of service and higher throughput can be provided only if all vehicles can use the road space available much more efficiently. A pre-condition for providing an efficient HCBS would be the provision of physically segregated lane for non-motorised traffic.

8. Unless commuting by bus is made safe from road accidents and crime for pedestrians and cyclists, it will be very difficult to attract more passengers as per capita incomes increase in our cities. Therefore, safety improvements should be an integral part of the HCBS.

9. Delhi has a wide network of arterial roads with right of way equal to or greater than 45 m. HCBS can be implemented on these arteries since all of them have high commuter demand.

10. Detailed guidelines for location of the dedicated bus way will have to be developed based on corridor conditions and international experience. Space around the busways would have to be pedestrian friendly, with segregation of different road users (especially slow moving traffic), and integrated with the existing system. The project should be seen as an urban development project and not just a bus project. Improvement in neighbourhoods will create a demand for such systems.
11. A special organisation would need to be established whose only job would be to carry out the high capacity bus system project. This arrangement would be essential for ensuring public-private partnership and coordination with all concerned agencies.

12. Use of public transport benefits all citizens of a city in terms of improved transport, reduced emissions per passenger transported and possibility of reducing deaths and injuries from traffic crashes. In view of this it is advisable for developing methods of raising finances from the citizens of a city for development of infrastructure and running the HCBS. Innovative ways of taxation and investments need to be explored, including charging a pollution tax from users of private vehicles.

13. Private operators are the preferred option wherever possible. However, these operators must be subject to the following:
    - No competition among them for attracting passengers.
    - There can be several large operators but using state infrastructure.
    - A regulatory authority that decides routes, fare structure, quality of buses, etc, must manage the operators.

14. Estimates made at TRIPP, Indian Institute of Technology suggest that infrastructure changes could be in the range of Rs. 1-3 crores per km depending on the corridor under consideration.

15. For HCBS to be successful, it has to made very attractive and full use of ITS and passenger information systems must be incorporated.

16. An agency conversant with integrated project management and evaluation should be given the job of preparing a project plan for HCBS systems for Delhi

ACKNOWLEDGEMENT

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