Bus Priority Lanes for Delhi

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ABSTRACT

Detailed field studies in Delhi show that 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. All modes of transport move in sub-optimal conditions in the absence of facilities for non-motorized vehicles. In this paper we illustrate that pedestrians, bicyclists and non-motorized rickshaws are the most critical elements in mixed traffic. If the infrastructure design does not meet the requirements of these elements all modes of transport operate in sub-optimal conditions. It is possible to redesign the existing roads to provide safe and convenient environment to non-motorized modes. This also results in improved efficiency of bus transport vehicles and enhanced capacity of the corridor when measured in number of passengers per hour per lane. The paper illustrates that the capacity achieved in a corridor by redesigning the road cross section, which includes segregated cycle tracks, and exclusive bus lanes compares favorably to capital intensive option like MRTS.

PUBLIC TRANSPORT

Buses form the backbone of the transport system in Delhi. Buses constitute less than one percent of the vehicle fleet, but serve about half of all travel demand. Since 1992, Delhi has turned increasingly to the private sector to help expand and improve bus service. This decision was a response to the widely acknowledged shortcomings of public bus service, including escalating costs, poor maintenance, high labour costs, an aging bus fleet, and erratic service. Bus service was expanded in 1996 by adding more buses, with buses per route increasing from 0.8 to 1.7.[1] The regular fixed-route bus system now comprises about 4,000 privately operated buses and 3,760 publicly operated buses. 5,000 private charter buses that provide point-to-point service during peak hours to subscribers who pay a monthly fee for a guaranteed seat complement it. The schools and tourists use another 5000 buses.

Public buses provide a low level of service and comfort, with passengers often travelling on footboards. Large-scale privatization may have increased capacity marginally, but buses continue to be overcrowded and poorly maintained. Even though buses carry half of all passenger travel, they receive no preferential treatment in terms of dedicated lanes or traffic management. Many Delhi residents cannot afford to pay even the low subsidized fares. Consider that a single one-way bus fare for people living on the outskirts of the city is \$0.20-\$0.25 (Rs.8 to Rs.10), depending on the number of transfers. For the poorest 28 percent of households with monthly incomes of less than Rs.2, 000, about US \$40(ORG, 1994), a single worker would spend 25 percent or more of their entire monthly income on daily round trip bus fare. For those with incomes much less than Rs 2,000, the already-low bus fare is prohibitively expensive.[2]

Bus commuters and pedestrians and NMV users together form the largest group of road users. Yet their needs for a safe and convenient infrastructure continues to be ignored. In the name of development cities continue to invest in infrastructure which makes the environment for pedestrian even more hostile than the present. At the bus shelters, NMV's using the carriageway are in direct conflict with buses and the approaching commuters. These buses park in platoons of 3 to 6 at an interval of 30 to 60 seconds. Thus for the cyclists, every bus shelter encountered, results in an increase in travel time and in the number of serious conflicts. To avoid an impending conflict at the bus shelter cyclists, either wait for the buses to clear their path or attempt to find their way slowly through a maze of buses and commuters. At many locations the passenger cycle rickshaw is one of the most important components of the commuting chain. The rickshaws ferry, passengers to and from the bus shelter, saving their walking trips. Currently the contribution of the passenger cycle rickshaw to the transportation system of the city is not recognized and thus no provision has been made for their parking at the bus shelters, forcing them to occupy the carriageway.

Rickshaws and Non-Motorised Vehicles

Cycle rickshaws are registered separately from motorized vehicles. Current policies regarding cycle rickshaws and other non-motorized vehicles are restrictive based on a notion held by many that efficient ("modern") transport systems do not include these vehicles. Traffic management experts and traffic police have proposed area and time restrictions on the movement of cycle rickshaws in Delhi. The government fixes the number of cycle rickshaws that can be registered in the city (by Municipal Corporation of Delhi) and at present this is 99,000. The registration procedure requires the owner to have a valid registration card, and to register these vehicles only during stipulated times twice a year. Not surprisingly, a large number of cycle rickshaws are unregistered. The true number of cycle rickshaws in the city is estimated to be about 300,000. Cycle rickshaws are also used for delivery of goods such as furniture, refrigerators, and washing machines. Several case studies have documented the poor, often exploitative, working conditions of cycle rickshaw operators. Contractors who demand a fixed rental payment from the pullers, often with little regard to the state of the equipment or the environment in which the rickshaw puller has to operate usually owns the vehicles.

Even though rickshaws and other non-motorized vehicles are widely viewed as a principal cause of congestion and chaos, they have been ignored in traffic planning and road design.

INADEQUATE 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 30m and greater than 30m. Nearly 500 km of these roads already exist, remaining 852 km is proposed in new developments. Ring road and Outer Ring road are the most important arterial roads. In general, most arterial roads are six lanes 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 hour mid block speeds tend to be much higher ranging from 50-90 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 problem lies with the poor management of the corridor traffic flow and speed resulting in increased levels of congestion are at few spots and few corridors at peak hours. The traffic system does not meet the requirements of pedestrians, bicyclists and bus systems.

The Basic Infrastructure

The road network in Delhi is based on notional hierarchy of roads, ranging from arterial roads designed to carry fast through traffic to collector and residential roads. However, the lack of choice results in pedestrian's presence on all roads regardless of the hierarchy and designated functions. The existing road design does not cater to the needs of pedestrians, bicycles, or any other slow moving traffic. Service roads if present, are not maintained well. Footpaths are either not present or poorly maintained. There are no specific facilities provided for buses also, except locating bus shelters. Approach to bus shelters, bus priority lanes, continuous pedestrian paths, lane for slow vehicles like bicycles and rickshaws etc. have not been included in the road network designs. Consequently all road users have to share the carriageway. This often leads to unsafe conditions for pedestrian and slow moving vehicles and congested conditions for motorized vehicles. The per capita availability of road in Delhi in 1997 was 2.6 meters per person. It must also be noted that almost 66% of the vehicular fleet in Delhi consists of motorized two wheelers which take up less road space than cars and buses. Despite this, average speeds have been reducing over the years. Peak hour traffic on arterial roads crawls through bottlenecks at major intersections. In general, most arterial roads are six lanes divided roads; however, the extensive road network has not been developed to serve the mixed traffic present on the roads.

State authorities and 'experts' continue to plan infrastructure, which ensures fast movement of car traffic at the cost of pedestrians, and non-motorized vehicles. Basic needs of pedestrians are not recognized as part of urban transport infrastructure. In a recent study (IIT, 2000) pedestrians were observed at selected junctions on a major arterial road in Delhi. The study shows that nearly 70% pedestrians cross the road when it is safe for them to cross, i.e. either it is green for pedestrians or green for right turning vehicles which makes half crossing safe. The number of pedestrians waiting at the median is more than those waiting on the side of the road; despite the absence of Pedestrian island in the median. The road median does not provide any convenient space for waiting, however, restrictive measures for pedestrians are instituted such as high medians (30-50 cms) and guardrails on medians. Often, construction of pedestrian subways and foot over bridges are to ensure that the pedestrians do not obstruct the motorized traffic and the road is available to motorized vehicles only. These poorly located pedestrian subways continue to have low usage rate not only because of poor location also because of safety concerns they are often locked at night. This leaves no option for pedestrians but to either break the median fences or run across at the risk of losing their life. Pedestrians have to contend with narrow pavements, often made narrow to increase the width of the road to reduce congestion for cars and other motorized traffic. Pedestrians are expected to walk among parked cars, electric and telephone poles, traffic signs, litter bins, redundant phone boxes, and commercial waste. The situation is made worse as a result of poor public management of streets and public spaces, including litter and uneven pavement. It is not wrong to say that our urban streets are characterised by an absence of design.

Presence of diverse socio-economic groups in the city is reflected in the diverse modes of transport present on all roads. This also results in emergence of range of activities required by different road users. Delhi does not lack in availability of roads infrastructure in terms of space and length. However, the complexity arises due to the wide variety of vehicle types including human, animal drawn vehicles and bicycles share the same road space. 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 the road space available can be used by all vehicles much more efficiently. At present, due to lack of dedicated facilities, bicyclists have to interact with fast moving motorized traffic. Clearly, the extensive road network has not been developed to serve the mixed traffic present on the roads. The society pays a huge cost in terms of worsening congestion, air pollution and traffic accidents. While the growing congestion and air pollution affect all income groups, the middle and lower income groups who are primarily dependent on public transport, bicycles and walking -the environment friendly modes have to suffer the unusually high cost of traffic accidents. Commuting patterns of low income and high-income people residing in Delhi are significantly different. Since nearly 50-60% of the city population resides in unauthorized slum settlements having an average income of Rs.2000/month, bicycles, buses and walking continue to be important modes of transport.

Infrastructure for Buses

Public transport buses are the major mode of transport in Delhi. Approximately 10,000 buses carry 6 million commuters along 600 routes everyday. However, the road design, traffic signals, and traffic management policies are not specifically designed for bus transport system. The design and location of the bus shelter itself does not meet the commuters requirements of providing convenient interchange between bus routes and spaces for hawkers. Therefore, often bus stops and bus shelters result in a major conflict zone between commuters and moving buses while hawkers “encroach upon” the carriage-way, and bicycles and other slow moving vehicles occupy the designated bus stops. At the bus shelters, NMV’s using the carriageway are in direct conflict with buses and the approaching commuters. These buses park in platoons of 3 to 6 at an interval of 30 to 60 seconds. Thus for the cyclists, every bus shelter encountered, results in an increase in travel time and in the number of serious conflicts. To avoid an impending conflict at the bus shelter cyclists, either wait for the buses to clear their path or attempt to find their way slowly through a maze of buses and commuters. At many locations the passenger cycle rickshaw is one of the most important components of the commuting chain. The rickshaws ferry, passengers to and from the bus shelter, saving their walking trips. Currently the contribution of the passenger cycle rickshaw to the transportation system of the city is not recognized and thus no provision has been made for their parking at the bus shelters, forcing them to occupy the carriageway.

Roadside vendors and services for road users

Bicycles, pedestrians and bus traffic attracts street vendors. Often the side roads and pedestrian paths are occupied by people selling food, drinks and other articles, which are demanded by these road users. Vendors often locate themselves at places, which 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 them were not required at those locations, then they would have no incentive to continue staying there. However, road authorities and city authorities view their existence illegal. Often the argument is given how the presence of street vendors and hawkers reduces road capacity. If we apply the same principle that is applied for the design of road environment for motorized traffic especially private cars, then vendors have a valid and legal place in the road environment. Highway design manuals recommends frequency and design of service area for motorized vehicles. 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. All modes of transport move in sub-optimal conditions in the absence of facilities for pedestrians and non-motorized vehicles.

THE 'CRITICAL' ELEMENT IN CITY TRANSPORT SYSTEM

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, land-use 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. Even at one-lane sites the bicyclists occupy the left extreme giving space to the motorized vehicular traffic.

A study of fourteen locations in Delhi shows that maximum mixing of NMVs and MVs occurs at the bus stops.[4] 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 3 lane roads. The flow for these urban localities can be taken as 2000 passenger car units per hour per lane.[5] Though the peak volumes are not exceeding saturation capacities, we find the average speed remains in the range of 14 to 39 km/h. This shows that use of the left most lane is only partially used. However, if this space were exclusively available for bicyclists throughput would increase because the MV traffic lane is 3.5 meters wide and it can accommodate flow rates of at least 6000 bicycles per hour.[6]

Though de facto segregation takes place on two and three lane roads, an unacceptable danger exists to bicyclists because of impact with MVs. At two- and 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. Our data show that bicycle fatalities on two and three lane roads are relatively high when traffic volumes are low but conflicts between MVs and NMVs have little correlation whatsoever with fatalities during peak flows. In these locations of "integrated" traffic on two and three lane roads, fatalities during peak hours are low but not eliminated. On the other hand, during non-peak hours vehicles travelling at speeds around 50 km/h or greater kill a large number of bicyclists.[4]

ROAD SECTON PLANNING FOR EXCLUSIVE BUS LANE

Our studies show that on urban arterials the curbside lane (3.5 m) is used primarily by bicycle and other non motorized traffic. Because of the presence of bicycles and NMVs in the far-left lane, buses are unable to use this lane and are forced to stop in the middle lane at bus stops. Motorized traffic does not use the curbside lane even when bicycle/NMV densities are low. A segregated bicycle lane needs only 2.5 m and since most of the major arterials in Delhi as well other Indian cities where planned development has taken place after 1960s, have a service road, the existing road space is wide enough to accommodate a bicycle track. This would not require additional right of way for road. A detailed study completed in Delhi, India shows how existing roads can be redesigned within the given right of way to provide for an exclusive lane for NMT modes (bicycles and three wheeled rickshaws).[7]

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

1. Physically segregated bicycle tracks on routes which have >30m ROW.
2. Recommended lane width on main carriageway 3m (minimum).
3. Recommended lane width for buses 3.3 m (minimum).
4. Recommended lane width for bicycles 2.5 m (minimum).
5. Separate service lane and footpath.
6. Intersection modification to include the following:
   - Restrict free left turns
   - Modify traffic signal cycle
   - Roadside furniture to ensure safe bicycle movement and minimise interference from motorized two wheelers

Exclusive bus lanes can be provided either as curbside bus lane (Figure1) or central two lanes physically segregated from rest of the traffic (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.

Capacity improvement = 21000 (present) persons/hr
45000 (estimated) persons/hr
Improved safety and pollution

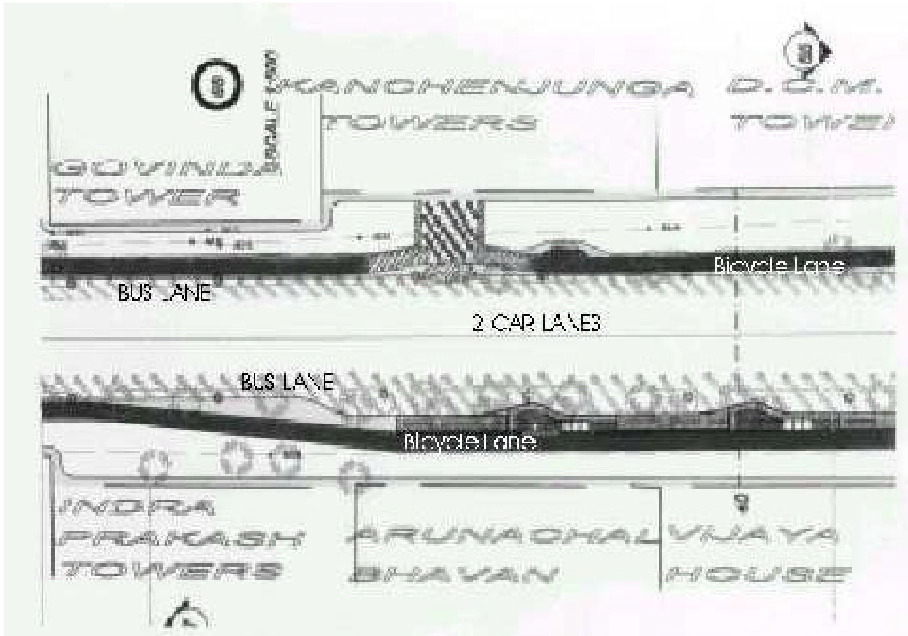

Fig. 1 Road layout showing exclusive curbside buslane

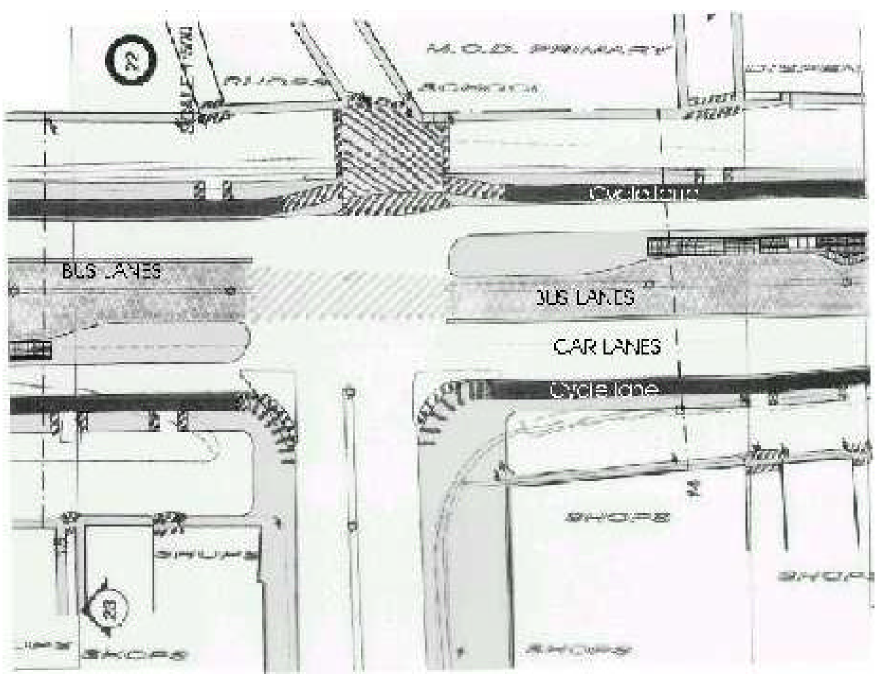

Fig. 2 Road layout showing central bus lane

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.	
E. g.	**Arterials through heavy commercial land-use areas like Vikas Marg**	**Highways through large institutional areas like stretch of Ring Road in ITO area.**

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.

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 The Minimum left turning radius according to which the curve of the intersection is plotted is 7.5m with a sloped leeway of

1.5m for larger vehicles. This case specific designing allows for control of left-turning speeds thus ensuring safety and the speed transition between an arterial and residential road.

Criteria for Locating Bus Stops Interchange should be close to their users. Bus and paratransit stops should be near to residences to minimize walking distance, and major interchanges should have direct pedestrian links segregated from motorized traffic.

Public transport routes should generally follow main traffic routes and boarding points should be adjacent to and beyond intersections and linked with other parts of the general traffic network - particularly footpaths. Measures should be taken to remove cyclist from the main carriageway, cause they prevent the buses from parking close to the bus stops or interchange points.

Bus and paratransit stops should be placed at points where pedestrian routes to and from major generators converge (example: major commercial, institutional centres or next to major intersections). Avoid locations where road safety or congestion problems are likely.

Wherever possible public transport vehicles should be provided with clearly marked passenger pick up points or bus stops, preferably off the main carriageway (i.e. bus stops should preferably be located on a lay by.

Lay-bys should be positioned on straight, level sections of road and should be visible from a good distance in both directions.

Access to a lay-by should be convenient and safe for both, vehicles and pedestrians.

Advance warning signs should be erected to alert the drivers of the approach to lay-bys and, the possible presence of pedestrians ahead.

Special facilities should be used in order to give greater priority to buses and hence to make public transport more attractive to potential passengers. These generally set aside a portion of the road for the exclusive use of buses, where they can maintain reasonable speeds or reach the head of the queues at intersections

If buses stop on the opposite side of the same road, stops should be located tail to tail as these are safer. Pedestrians will tend to cross behind the buses where approaching vehicles on the same side of the road can see them more carefully.

Bus stops should be located beyond pedestrian crossings and after intersections to avoid stopped vehicles masking pedestrian and other crossing activities.

Bus Stops should be placed such, around an intersection, so that the walking distance from the crossing reduces for the commuters. The walkable distance in each direction can be reduced to as low as 50m.'s by removing all free left turns and placing the bus stops after the crossing (in each direction of traffic flow).

Criteria for Redesigning Bus Stops 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.

CAPACITY ESTIMATES

If a separate segregated lane is constructed for bicycles, the curbside lane, which is currently used by bicyclists will become available to motorized traffic. This relatively small investment in bicycle lanes can increase the road space for motorized traffic by 50 percent on 3 lane roads. Bicycle lanes also result in better space utilisation. For instance a 3.5m lane has a carrying capacity of 1,800 cars per hour whereas it can carry 5,400 bicycles per hour. Average occupancy of a car is 1.15 persons [i]and bicycle carries one person. This implies that in order to move the same number of people we would need 2.6 times the road area that would be required for bicyclists.

Most of the major corridors in Delhi are 6 lane divided carriageways. We have estimated the capacity of a 6 lane divided carriageway in the peak direction. Various combinations of modal shares and road space assignments were compared to evaluate their impact on the road capacity. Following options were considered:

Base case (Mixed traffic). The existing road space utilization pattern was taken as the base case. Capacity of a typical 6-lane corridor in Delhi corridor in persons per hour is estimated on the basis of average occupancy of each vehicle (Table2).

Dedicated cycle lane. The right-of-way on a 6-lane carriageway is reallocated to provide for a separate 2.5-3 m wide bicycle track. The exclusive bicycle track can carry 4500 bicycles per hour. This still leaves enough space for six lanes on the main carriageway. All the lanes of the main carriageway are used by all motorized modes. If the space released by exclusive bicycle track (equivalent of 338 bicycles ~ 169 PCU~76 buses as per Table2) is used by additional 76 buses the congestion level and corridor speed will not have significant changes. Table 2 shows increase in corridor capacity from 16000 to 19000. Number of bicycles and other vehicles remain same as the base case. Buses increase by 76 additional vehicles.

Dedicated bicycle lane and high capacity bus system (HCBS). 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 3 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 per cent.

It is clear that, if Delhi and other similar cities can have major improvement in public transport capacity if facilities for non-motorized transport are considered as an integral part of a programme to enhance road capacity. Not only are lanes designed for bicycle traffic less expensive to build than roadways, but they also will divert pedestrians and slow-moving vehicles from the roadway, increasing the efficiency of car and bus transport.

Table2: Capacity Estimation in different scenario

Current				Exclusive Cycle track provided		Cycle track and HCBS			
Vehicles/h		Persons/h			Persons/h	Persons/h		Persons/h	Persons/h
		Bus=40	Bus=80	Veh./h	Bus=40	Bus=80	Veh./h	Bus=40	Bus=80
Cars	1404	1615	1615	1404	1614	1615	1404	1615	1615
MTW	1652	3634	3634	1652	3634	3634	1652	3634	3634
BUS	248	9920	19840	324	12960	25920	486	19440	38880
TSR	454	799	799	454	799	799	454	799	799
Cycle	338	355	355	338	354	355	4500	4725	4725
Total	4096	16323	26243	4172	19363	32323	8496	30213	49653
	~	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 b y 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

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	1615	1615	1615	1615
MTW	3634	3634	3634	3634
Bus	12960	25920	19440	38880
TSR	799	799	799	799
Total	19008	31968	25488	44928
~	19000	32000	25000	45000

AVOIDED COSTS DUE TO INVESTMENTS IN PEDESTRIAN, BICYCLE AND PUBLIC TRANSPORT FRIENDLY INFRASTRUCTURE

Detailed origin and destination studies of bicycle users show that all roads should become NMV/public transport friendly. Since Delhi has an extensive network of arterial roads which have wide right of way (30m to 90m), these offer the opportunity of developing a physically segregated network. Other narrow streets, primarily residential and collector roads have to become NMV-friendly with the help of traffic calming devices. The development of public transport/NMV friendly infrastructure can be prioritized as follows:

Phase I: Approximately 90 kms of arterial route has been identified as carrying heavy bicycle traffic along with large numbers of buses and trucks. A separate bicycle path on such routes will ease the flow of buses and other motorized traffic.

Phase II: Almost 276 kms of road length has been identified as carrying fast motorized traffic (average speeds are more than 50 kms and maximum speeds 70-80 kms) in the presence of bicycles on the curb side of the road. A well designed network will ensure safety of bicyclists on these routes. It will also result in improved capacities for motorized vehicles by providing an opportunity for creating an exclusive bus lane on these routes.

Phase III: There are 368 kms of roads in the city which has more than 30 m right of way. Separate bicycle path on these roads will ensure continuity of network.

Phase IV: Bicycle routes should be developed through parks and green belts. This would provide additional capacity for bicycle network.

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 rickshaw parking. These designs benefit all road users.

Estimated modal shifts after investment in public Transport/NMV friendly infrastructure

If public transport/NMV friendly infrastructure is developed in the city, following change may occur in the use of different vehicle use.

1. Short bus trips (1-6 kms) these will be primarily younger age group (15-24years) will include school trips and leisure trips of children and young adults. Short bus trips of working adults (24-60 years) can also be targeted for substitution. Shift from bus trips will generate capacity in the present overloaded bus system. It may not reduce demand for number of buses, in fact comfortable conditions in buses may make public transport attractive to two wheeler riders and few long trips (16-25kms) of two wheelers may move to buses. Therefore this will result in higher share of bicycle trips (from 2.75 to 5 per cent), reduced share of motorized two wheeler trips(from 29 to 25 per cent) and marginally higher share of bus trips(36 to 37 per cent) .

2. Short car trips (1-6) kms of children and adults can also be targeted as in 1. If 1/3 of short car trips are replaced by bicycles, there will be an increase of 1.68 per cent bicycle trips, i.e from 5 to 6.68 per cent, car trips will reduce to 26.6%.

3. Short motorized two wheeler trips say 1/3 of short trips (1-6kms) will shift to bicycles increasing bicycle share by 2.5 per cent from 6.68 to 9.18 per cent. Motorized two wheeler trips will reduce to 22.5 per cent.

4. Pedestrian trips more than 1km in length of all age groups and all income groups. This will result in marginal increase of bicycle trips because majority of the pedestrian trips are less than 1 kms long.

Table 4 shows estimated change in modal shares of Delhi residents excluding people living in JJ clusters. Table5 shows estimated change in modal shares of Delhi residents including JJ clusters residents when the share of JJ cluster resident is 60 per cent of the total population and when it is 50 per cent percent of the total population. Modal shares have been estimated for both cases, since reliable numbers for this are not available. In both cases the estimated modal shares indicate the reduction in car and two wheeler traffic and increase in bicycle and pedestrians. Share of buses does not show any significant change, however the bus ride is expected to become more comfortable and convenient.

Table 4: Estimated Change in Modal Share in Delhi

Mode	Present Modal Share (1999)(%)**	Estimated change in modal share (%)
Cycle	2.75	10
Bus	36.2	37.65
Car	28.35	26.5
SC/MC	29.29	22.5
Auto	1.74	1.75
Walk	1.62	1.6
Total	100	100

** IIT survey

Table5: Estimated change in modal shares (after investment in bicycle infrastructure)

Mode	% of low income population 60%		Share of low income population 50%	
	Total trips	%share	Total trips	%share
Cycle	6.39	27	5.72	24
Bus	7.94	34	8.08	35
Car	2.48	11	3.10	13
SC/MC	2.45	10	2.92	12
Auto	0.30	1	0.32	1
Taxi	0.00	0	0.00	0
Rail	0.25	1	0.21	1
Others	0.33	1	0.27	1
Walk	3.26	14	2.78	12
Total	23.40	100	23.40	100

BENEFIT ESTIMATION

Increased Capacity

If a separate segregated lane is constructed for bicycles, the curbside lane, which is currently used by bicyclists becomes available to motorized traffic. This relatively small investment in bicycle lanes can increase the road space for motorized traffic by 50 percent on 3 lane roads. Bicycle lanes also result in better space utilisation. For instance a 3.5m wide lane has a carrying capacity of 1,800 cars per hour whereas it can carry 5,400 bicycles per hour.[6] Average occupancy of a car is 1.15 persons[8] and bicycle carries one person. This implies that in order to move the same number of people we would need 2.6 times the road area that would be required for bicyclists. 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, which are more efficient in terms of space utilisation.

Motorized vehicles benefit because of improved capacity of the road and improvement in speeds. Capacity estimations of a typical arterial road in Delhi (Tiwari, 1999) show improvement in corridor capacity by 19-23% by providing an exclusive cycle track. If the full capacity of the corridor is utilised, i.e., provision of a high capacity bus lane in the left most lane can lead to capacity improvement by 56-73%(present carrying capacity of 23,000 passengers/h to 45,000 passengers/h).

Improved speeds

Improvement in speeds of motorized vehicles will be experienced until the corridor is full to capacity due to realisation of induced demand. Major beneficiaries of speed improvement are buses and two wheelers because curbside lane becomes 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[10] show 48% reduction in time costs due to 50 per cent improvement in bus speeds (from present 15km/h to 30 km/h) and 30 per cent improvement in car and two wheelers.

Reduced congestion

Congestion has long been recognised as an environmental problem. Other than causing delay, it causes noise and fumes and increases health risks of 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 show that re-planning the junction to include separate NMV lanes and bus priority lane can bring in 80 per cent improvement over the present level of delays. Cost of this measure is 25 times less than the proposed grade-separated junction.[11]

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 segregated facility reduces injury accidents by 40% and fatalities by 50%.[10]

CONCLUSIONS

Public transport vehicles and non-motorised modes are the major modes of transport for majority of the city residents. The existing socio-economic patterns and land-use distribution ensures NMVs presence in the whole city, and on the complete road network. The densities and modal shares of NMVs in total traffic may differ from one part of the city to the other. However, as long as NMVs are present on the road, regardless of their numbers, all vehicles move under sub-optimal conditions. Efficient bus system cannot be designed without taking care of the slow vehicles (NMVs) on the road. . It is possible to redesign the existing roads to provide safe and convenient environment to non-motorized modes. The guiding principle of the proposed design is to meet the needs of pedestrians and bicyclists in terms of convenience, safety, and comfort. This requires not only altering road geometry and traffic management policies but also legitimising the services provided by hawkers and informal sector. The road network- straight roads and intersections- geometry has to be designed from the perspective of the pedestrians, bicyclists and public transport vehicles. This enables the existing space to be reorganised for giving priority to public transport-exclusive bus lanes, better designed bus shelters, spaces for vendors, and rickshaw parking. These designs benefit all road users. This also results in improved efficiency of bus transport vehicles and enhanced capacity of the corridor when measured in number of passengers per hour per lane, substantial reduction in fatalities and vehicular emissions.

Since sustainable transport systems in Indian cities demand moving a large number of people by bus transport and NMVs, planning for NMVs is indispensable.

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