ABSTRACT

To ensure safety and smooth movement of all modes of transport there is a strong case for developing a bicycle and pedestrian friendly transport infrastructure as an integral part of the urban transport network. Detailed field studies have shown that motorised vehicles do not use the left most lane even when bicycle flow rates are very small. This affects the overall capacity of the road, because one whole lane is not used by the motorised vehicles. However, the natural segregation of bicyclists, pedestrians and other non-motorised vehicles (NMVs) does not ensure their safety on two and three lane roads.

Even a subsidised public transport system remains cost prohibitive for a significant segment of the population. According to the ORG 1994 survey, approximately 28% of the households in Delhi have a monthly household income of less than Rs. 2000. For these people, bicycling and walking are the only logical choices. A well designed bicycle infrastructure can reduce the hardships faced by this section of the population if a separate segregated lane is constructed for bicycles, the curb-side lane, which is currently used by bicyclists will become available to motorised traffic. This will lead to an increase of about 50% in the capacity of the existing three-lane road network. Thus a relatively small investment in bicycle lanes which can increase the road space for motorised traffic significantly. This will also make it possible to provide for dedicated bus lanes. **However, the segregated bicycle lane has to be made attractive for bicyclists with the help of various traffic calming measures which increases their safety and also gives them priority over motorised vehicles on these paths.**

BACKGROUND

Bicycles are a means of transport. Bicycle users make journeys between the same kinds of places for the same purposes as users of other modes of transport. cyclists need to be able to proceed to their destination with minimum efforts, inconvenience and danger.

For all transport modes, the most direct feasible routes between housing areas, shops, work places, schools and leisure attractions are usually served by existing roads. However, the layout of all-purpose roads combined with the quantity size, speed and complexity of manoeuvre of motorised traffic can have a huge impact on the convenience and safety of cycle users.
Unlike other urban areas in India the majority of the population in Delhi is not dependent on bicycles for daily commuting, however cycle traffic can contribute up to 34% of the total traffic depending on the corridor. The proportion of cycle traffic has been observed to be more than 30% of the total traffic in the peak hours on many arterial roads.

On one of the most important highways (Rohtak Road) cycles constitute 43% of the total traffic in peak hour.

The share of bicycle traffic continues to be substantial despite lack of planned facilities for them. Consequently,

1. Bicyclists are exposed to higher risks of getting involved in a road traffic crashes. Bicyclists constitute 14% of the total road traffic fatalities in Delhi.

2. On two and three lane roads de facto segregation occurs naturally and the bicyclists occupy the curb-side lane. However, this natural segregation of bicyclists does not ensure their safety on two and three lane roads.

3. Motorised vehicles do not use the left most lane even when bicycle flow rates are low. This affects the overall capacity of the road, because one whole lane is not used by the motorised vehicles.

4. The road surface which is designed for motorised vehicles is used by bicycles and other non-motorised modes. This amounts to wasting resources because non-motorised modes require pavements which can be constructed more economically.

Clearly there is a strong case for developing a bicycle master plan for Delhi as an integral part of the urban transport network. Some of the other important issues which support the case for developing a master plan for bicycles are:

1. Captive ridership: Share of bicycle trips as a proportion of the total trips has declined over the years. However, a large number of commuters are still using bicycles and other non-motorised mode of transport in spite of long trip lengths. For example, in outer areas of Delhi, non-motorised vehicles and pedestrians are present on most intercity highways and have comparatively long trip lengths. This shows that at present a large number of people use these modes not out of choice but owing to absence of other options.

Even a subsidised public transport system remains cost prohibitive for a significant segment of the population. Assuming a minimum of 4 trips per household per day at the cost of two rupees per trip for public transportation, a household would need to spend Rs. 320 (Rs 43= US $ 1) per month on transportation. For low income people living on the outskirts of the city, the cost per trip may be Rs. 4 to Rs. 6 depending on the number of transfers. On an average, a low income household cannot spend more
than 10% of its income on transportation. This implies that a household's income must be at least Rs. 3200 to be able to use the public transport system at minimum rates. According to the ORG 1994 survey, approximately 28% of the households in Delhi have a monthly household income of less than Rs. 2000. For these people, bicycling and walking are the only logical choices. A well designed bicycle infrastructure can reduce the hardships faced by this section of the population.

2. Reduced pollution and energy consumption: Motor vehicles are reported to be the single largest source of air pollution causing 70% of the total air pollution in Delhi. This is a serious concern to cyclists, pedestrians and motorists as air quality is worse in or near built up roads. Cyclists suffer the adverse affects of pollution because of heavier breathing whilst exercising close to the source of exhaust pollution. A dedicated infrastructure can reduce this problem to some extent. While motorised transport is one of the most polluting of all human activities, however, cycling is the least polluting mode of all. Cycling generates no noise pollution or toxic emissions. Therefore, there is a need to make cycling more popular than the existing levels. A better bicycle infrastructure can play an important role in increasing the modal share of bicycles and thus, reduce the air pollution and increasing adverse health affects of pollution. Separation of bicycle and other non-motorised traffic would result in smoother flow of motorised vehicles resulting in lower emissions.

3. Bus Lanes: Segregated bus lanes are necessary to meet the increasing travel demand and to improve the public transport service. Except in few urban corridors where the centre of the road is reserved for buses, in many cities around the world, the curb side lane is reserved for buses. The latter has been attempted in Delhi, but with no success. In the absence of segregated bicycle lanes bicyclists use the curb-side lane. This makes it impossible for buses to use the left-most lane in spite of repeated attempts at enforcement by the Delhi Police. If separate lanes were available then all bicyclists would use them and this would make the curb-side lane available for buses. As a matter of fact, the presence of segregated bicycle lanes is a necessary pre-condition for establishing bus lanes.

4. Increased capacity: If a separate segregated lane is constructed for bicycles, the curb-side lane, which is currently used by bicyclists will become available to motorised traffic. This relatively small investment in bicycle lanes can increase the road space for motorised 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. This implies that in order to move the same number of cars we would need three 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.
5. **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. Congestion and cycling policies are interconnected in two ways. Firstly, because congestion leads to worsened air quality and a poor environment, it may act as a deterrent to bicyclists. Secondly, policies which promote bicycling would in themselves help to relieve congestion because cyclists require so much less road space than motorists, both when travelling and parking.

6. **Increased safety**: By creating segregated bicycle lanes and by proper design of intersections, conflicts between motorised traffic and bicyclists can be reduced substantially leading to a sharp decrease in the number of accidents and fatalities for bicyclists and motorised two-wheelers.

**THE BASIC INFRASTRUCTURE**

A well-functioning bicycle infrastructure which is the key to a longer lasting safe road-traffic system primarily requires two design principles:

1. Arterial roads which have more than 30 m right of way (ROW) must have physically segregated bicycle/non-motorised vehicles (NMV) path, which cannot be used by motorised vehicles (especially motorised two-wheelers).

2. Average speeds on roads which have less than 30 m ROW must be brought to 20-30 kms/h with the help of traffic calming measures.

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

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

The proposed plans have focused at the three levels of bicycle facilities as follows:

(a) Network route planning
(b) Road section planning
(c) Intersection planning

(a) **Network route planning**

A cycling-network has the shape of a series of links and junctions. It is necessary that a network satisfies the needs of bicycle-traffic as much as possible. Detailed origin destination analysis of bicycle users shows that there is a need for a continuous network for bicyclists covering the whole of Delhi because there are no areas where they are not present. The proposed routes must guarantee a coherent network structure, minimise trip length (directness) and minimise the number of encounters between cyclists and motor-vehicles (safety).
Since Delhi has an extensive network of arterial roads which have wide right of way (30 m to 90 m), these offer the opportunity of developing a physically segregated network. Other narrow streets, primarily residential and collector roads have to become bicycle friendly with the help of traffic calming devices.

The development process can be prioritised to meet the three objectives of the bicycle masterplan. Bicycle network should be developed in the following phases:

**Phase I:** Approximately 90 km 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 motorised traffic. This should be developed in the first phase because this would result in improving flow of bicycles as well as public transport buses and motorised private modes which are affected by the presence of bicycles on the same carriageway.

**Phase II:** Almost 276 km of road length has been identified as carrying fast motorised traffic (average speeds are more than 50 km and maximum speeds 70-80 km) 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 motorised vehicles by providing an opportunity for creating an exclusive bus lane on these routes. These are the major arterials which carry fast traffic. In non-peak hours and at night when the visibility is poor, bicyclists are exposed to a high risk of getting involved in fatal accidents on these roads, therefore a well designed network will ensure safety of bicyclists on these routes. Phase II includes 4 radials and 2 ring roads in the city.

**Phase III:** Roads with 30 m ROW will be developed as a part of bicycle network level plan in this phase. There are 368 km 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:** In the fourth phase bicycle routes are proposed through parks and green belts. This would primarily be additional network capacity for bicyclists.

A well functioning bicycle infrastructure is the key to a longer lasting safe road-traffic system. Bicycle network which is to be developed in the city must fulfil the following objectives:

1. Traffic flow of all vehicles using that corridor should improve.
2. Number of accidents involving bicyclists should reduce.
3. Potential bicyclists should be encouraged to use bicycles.

A study has been completed which includes details of two corridors in Delhi – Preet Vihar to Connaught Place and Wazirabad Bridge to Nand Nagari. These have been redesigned keeping in mind the broad philosophy of the proposed network system.

**(b) Road-Section planning**

On designing road-sections it must be appreciated that cycle-traffic should be encouraged and that cyclists are vulnerable road-users who deserve extra protection wherever possible. Figures 1 and 2 show details of two types of cross sections, having central bus lanes or side bus lanes respectively. Both cross sections have the following geometric features:

1. 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.
2. 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)
3. A service lane is proposed between the cycle track and the peripheral footpaths all along the stretch with a minimum specified width of 3m.
<table>
<thead>
<tr>
<th>Med carriageway</th>
<th>bus lane</th>
<th>cycle</th>
<th>service lane</th>
</tr>
</thead>
<tbody>
<tr>
<td>f.p.</td>
<td>2x3m</td>
<td>3.3m</td>
<td>2.5m</td>
</tr>
<tr>
<td></td>
<td>&gt;3m</td>
<td></td>
<td>1.5m</td>
</tr>
</tbody>
</table>

**PROPOSED CROSS-SECTION**

*Figure 1: Design of NMV lane and bus lane on urban arterial*
Figure 2
The choice of central or side bus lanes depends on many factors as listed in the following Table 1.

**Table 1: Criteria for site specific choice between a central bus-lane layout and a curb-side bus-lane layout**

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>CENTRAL BUS LANE</th>
<th>CURB-SIDE BUS LANE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Excessive side-entries for vehicles into service lanes or individual plots.</td>
<td>Limited access to service lanes or widely spaced entry points into adjoining area.</td>
</tr>
<tr>
<td>Rationale</td>
<td>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.</td>
<td></td>
</tr>
<tr>
<td>2.</td>
<td>Closely placed traffic lights for vehicles.</td>
<td>Traffic lights at larger intervals.</td>
</tr>
<tr>
<td>Rationale</td>
<td>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.</td>
<td></td>
</tr>
<tr>
<td>3.</td>
<td>Low frequency of bus-stops</td>
<td>Higher Frequency of bus-stops</td>
</tr>
<tr>
<td>Rationale</td>
<td>If the frequency of bus-stops is higher a central bus-lane will create too many pedestrian crossings defeating its purpose while a curb-side bus lane will provide safer and more efficient bus-stops.</td>
<td></td>
</tr>
<tr>
<td>Rationale</td>
<td>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.</td>
<td></td>
</tr>
<tr>
<td>Eg.</td>
<td>Arterials through heavy commercial landuse areas like Vikas Marg</td>
<td>Highways through large institutional areas like stretch of Ring Road in ITO area.</td>
</tr>
</tbody>
</table>

(c) Junctions/Intersections planning:

Junctions present the most problems concerning the safety and comfort of cyclists.

Safety can be ensured on an intersection by a number of ways that have to work in conjunction such as:

- Giving forewarning of the approaching junction and what the drivers are expected to do.
- Reducing ambiguity in the drivers’ expectation by making clear the design of the junction and increasing directional understanding.
- Ensuring reduced speeds by design so that the driver has
  1. time to respond to the potential conflict,
  2. control of his vehicle at all times
  3. reduce fatality of accidents if any.
- The drivers should be warned that they are expected to slow down.
All the above strategies are implemented through the following measures:

**Ground design:** The flow, speed and direction of traffic is controlled by the design of the junctions and road surfaces. The design differs completely in the case of Curbside Bus Lane and Central Bus Lanes options.

**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 minor road.
- The design of the intersection specifically ensures the safety of the cyclists and pedestrians crossing over because the intersections are the only points where the cyclists are exposed to vehicular traffic and thus endangered. There are wide storage spaces at all corners of the junctions for cyclists and pedestrians to wait before crossing over. While the vehicular traffics stops before the stop line (5m before the junction), the cyclists have a demarcated area after the stop line. This allows them to follow the same signal cycle but gives them the extra initial start-up time they need. Figure 2 gives these details.

**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.
- The design of the intersection specifically ensures the safety of the cyclists and pedestrians crossing over because the intersections are the only points where the cyclists are exposed to vehicular traffic and thus endangered. There are wide storage spaces at all corners of the junctions for cyclists and pedestrians to wait before crossing over. While the vehicular traffics stops before the stop line (5m before the junction), the cyclists have a de-marked area after the stop line. This allows them to follow the same signal cycle but gives them the extra initial start-up time they need. Figure 2 gives these details.
Criteria for redesign of roundabouts:
The roundabout is redesigned to give right of way to cyclists and pedestrian who normally find it very difficult to cross this junction.

1. The cycle track is designed as an elevated ring around the circle inclusive of the peripheral footpaths and medians where it crosses them. These medians and footpaths become storage spaces necessary for the cyclists to wait before crossing over.

2. The elevated track, when it crosses the main carriageway, becomes a speed-breaking hump for the vehicular traffic to slow them down before they enter and after they exit the ring.

Treatment of junctions where side road or service road meets the cycle track:
The complete junction area is designed as a raised (150 mm) crossing. Cyclists have a gentler slope (1:20) compared with that for motorised vehicle. Changed texture, and raised platform improves visibility of the conflict area. Cyclists also become aware of the conflict zone because of ramp leading to the raised crossing zone. This is illustrated in Figure 3.

*Figure 3: Design of urban arterial at midblock with NMV lane, bus lane and bus stop*

Capacity improvement=21000 (present)persons/hr
45000(estimated)persons/hr
Improved safety and pollution
Capacity estimates \textsuperscript{ix} and cost estimates \textsuperscript{x} of the proposed cross sections show that corridor capacity improves by 19-23\% by providing an exclusive cycle track (from 26000 persons/hr to 32000 persons/hr. If the full capacity of the corridor is utilised, then 56-73\% capacity improved can be realised. Physical segregation of non-motorised vehicles on mid blocks will also improve safety of these vehicles because 70\% of the crashes involving bicycles and pedestrians are mid block crashes. Physical segregation would eliminate the interaction between NMVs and MVs thus reducing the probability of traffic crashes involving NMVs on these roads.

Cost estimates show that approximately Rs. 26.9 million per km are required to develop the proposed estimates. This compares very favourably with some of the other capacity improvement measures suggested in the city such as an underground metro (MRTS) construction. A capital investment in 1 km of MRTS is equivalent to the construction of 100 km of proposed new cross sections.

CONCLUSIONS

To ensure safety and smooth movement of all modes of transport there is a strong case for developing a bicycle and pedestrian friendly transport infrastructure as an integral part of the urban transport network. Such a network can be developed by applying traffic calming measures on arterial road junctions and cross sections to ensure safety and mobility of non motorised vehicles.

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