Road Designs for Improving Traffic Flow

A Bicycle Master Plan for Delhi

Geetam Tiwari

INDIAN INSTITUTE OF TECHNOLOGY DELHI
Acknowledgements

A team of transportation planners and engineers from IIT (Delhi) worked on this project to develop a bicycle master plan for Delhi. The project was sponsored to bring out detailed design solutions for the existing roads to improve flow of all modes of transport—public transport buses, private cars and two-wheelers as well as non-motorised modes—plying on the roads.

A large number of people from different disciplines have directly or indirectly contributed to the project development and completion of the first phase. The project team is specially grateful to Shri Rajendra Gupta, Minister Transport, Government of NCT Delhi, Ms Kiran Dhingra, Commissioner, Transport, Government of NCT Delhi, and officials from Delhi Development Authority, New Delhi Municipal Corporation and Transport Department NCT Delhi for participating in the workshops and sharing their valuable field experiences.

During the course of the study, team members interacted closely with experts from India and other countries. The team would especially like to acknowledge bicycle experts working at I-CE (Interface for Cycling Expertise, The Netherlands) for sharing their valuable international experience.

The project team held several meetings with people living in jhugi jhopdi clusters and ‘unauthorized colonies’ in Delhi. I am indebted to the people who interacted with the team and gave further insights for improving the bicycle plan.

I would also like to thank students, staff and faculty of TRIPP for their co-operation and assistance throughout the project.

Geetam Tiwari
**Project Team**

The following persons have worked on this project at various stages

**Dr Geetam Tiwari**, IIT (Delhi)
*Project Coordinator*
Transportation Planning

**Professor Dinesh Mohan**, IIT (Delhi)
*Co-Project Coordinator*
Traffic Safety, Biomechanics

**Dr Rajeev Saraf**, Lepton Software
*Consultant*
Traffic Engineering and GIS

**Mr Rajesh Patel**, Inventech
*Consultant*
Product Design

**Mr Praveen Nahar**, IIT (Delhi)
*Project Associate*
Product Design

**Ms Anvita Anand**, IIT (Delhi)
*Project Associate*
Architecture

**Mr Sandeep Gandhi**, IIT (Delhi)
*Project Associate*
Architecture

**Mr Birendra Kumar**, IIT (Delhi)
*Project Associate*
Civil Engineering

**Mr Mahesh Gaur**, IIT (Delhi)
*Data Processor*

**Mr Shiv Janardhan**, IIT (Delhi)
*Project Assistant*

**Mr Krishan Kumar**, IIT (Delhi)
*Project Assistant*
A Case for a Bicycle Master Plan for Delhi

Bicycles are used for journeys which are similar in nature and purpose to other modes of transport. Therefore, cyclists should be able to travel with minimum effort, inconvenience and danger. The most direct feasible routes of travel are usually served by existing roads. However, the layout of all-purpose roads combined with the size, speed and complexity of manoeuvre of motorized traffic can have a huge impact on the convenience and safety of cycle users.

Unlike other urban areas in India, majority of the population in Delhi is not dependent on bicycles for daily commuting though cycles contribute up to 34 per cent of the total traffic depending on the corridor. The proportion of cycle traffic has been observed to be more than 30 per cent of total traffic during peak hours on many arterial roads. On one of the major highways (Rohtak Road), cycles constitute 43 per cent of the total traffic during peak hours.

The share of bicycle traffic continues to be substantial despite the lack of planned facilities for them. Other factors that support the case for developing a dedicated infrastructure for bicyclists as an integral part of the urban transport network are:

- Captive ridership: The share of bicycle trips as a proportion of the total trips has declined over the years. However, a large number of commuters still use bicycles and other non-motorized vehicles (NMV) despite long trip lengths. For example, in outer areas of Delhi, non-motorized vehicles and pedestrians are present on most intercity highways and have comparatively long trip lengths. A large number of people use non-motorized modes of transport due to an absence of other viable options.

- Reduced pollution and energy consumption: Motor vehicles are reported to be the single largest source of air pollution causing 70 per cent of the total air pollution in Delhi. A subsidised public transport system remains cost prohibitive for a significant segment of the population. Let us assume that a trip on any form of public transport costs Rs 2 and a minimum of 4 trips are made per household per day, such a household would be spending at the very least Rs 320 per month on transportation. This amount could very well increase for lower income groups living on the outskirts of the city, in such cases the cost per trip would vary between Rs 4 and 6, the exact daily expenditure would depend on the number of transfers. On an average, a low income household cannot spend more than 10 per cent of its income on transport. Thus the 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, 28 per cent of households in Delhi have a monthly household income of less than Rs 2000. For these people, bicycling and walking are the only options. A well designed bicycle infrastructure can reduce the hardships faced by this section of the population.

1 Central Road Research Institute (CRRI), Development of traffic and transport flow database for road system in Delhi Area, 1990.
3 Tiwari Geetam, 'Nonmotorised transport in urban areas: on the verge of extinction or hope for the future?', Indian Highways, Sept 1995.
5 Central Pollution Control Board, Pollution statistics in Delhi, Ministry of Environment and Forests, New Delhi, 1993.
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 while cycling close to the source of exhaust pollution. A dedicated infrastructure can reduce this problem to some extent. While motorized transport is highly polluting, cycling is the least polluting mode of transport. Cycling generates no noise pollution or toxic emissions. Therefore, there is a need to make cycling more popular. A better bicycle infrastructure can play an important role in increasing the modal share of bicycles and thus reduce the air pollution and stem the tide of the increasing adverse health effects of pollution.

Bus lanes: Segregated bus lanes are necessary to improve the public transport service in order to meet the increasing travel demand. Except in some 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 curb-side lane despite 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.

Increased capacity: If a separate segregated lane is constructed for bicycles, then the curb-side lane, 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 per cent on three lane roads. Bicycle lanes also result in better space utilization. For instance a 3.5 m lane has a carrying capacity of 1,800 cars per hour whereas it can carry 5,400 bicycles per hour.  

Reduced congestion: Congestion has long been recognised as an environmental problem. Other than causing delay, it causes noise, fumes and increases health risks of road users and residents. Congestion and cycling policies are interconnected in two ways. Firstly, congestion leads to worsened air quality and a poor environment, it may act as 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 in terms of travelling and parking.

Increased safety: Of the total road fatalities, 14 per cent involves bicyclists. De facto segregation takes place on two and three lane roads whereby bicyclists occupy the curb-side lane but natural segregation does not ensure the bicyclists’ safety. By creating segregated bicycle lanes and through proper design of intersections conflicts between motorized traffic and bicyclists can be reduced substantially leading to 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.

At present, due to the lack of a dedicated bicycle infrastructure, natural segregation of traffic takes place thus bicycles use the curb-side lane of roads. Consequently, even when the bicycle flow rate is low, motorized vehicles (MV) do not use the curb-side lane. This adversely affects the overall capacity of the road.

Increased safety: Of the total road fatalities, 14 per cent involves bicyclists. De facto segregation takes place on two and three lane roads whereby bicyclists occupy the curb-side lane but natural segregation does not ensure the bicyclists’ safety. By creating segregated bicycle lanes and through proper design of intersections conflicts between motorized traffic and bicyclists can be reduced substantially leading to 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.

a sharp decrease in the number of accidents and fatalities involving bicycles and motorized two-wheelers.

Optimal utilization of resources: It is expedient to have a dedicated infrastructure for bicycles in terms of the cost of laying road surfaces. Bicycles and other non-motorized vehicles (NMV) do not require the same expensive and resource intensive pavements as heavy motorized vehicles.

**International Scenario**

The quality of urban environment has deteriorated seriously owing to noise, air and visual pollution, and inadequate road safety. This is particularly true in big cities which experiences the cumulative effect of all adverse consequences. The main cause of air pollution is motorized vehicles. Most of the pollutants present at the street level originate from motor vehicles. Realizing the potential and benefits of bicycling to the individual and environment, many cities in Europe have embarked on large scale projects to make their cities bicycle-friendly. In some cities of Europe, like Delft, Groningen, Copenhagen, more than 12 per cent of urban journeys are made on bicycles while the corresponding figure for Delhi is 6 per cent (see Table 1). This is in spite of the fact that most European cities are not very conducive for bicycling in terms of topography and climate. Bicycle master plans were created and implemented and bicycle policy was made as an integral part of their transportation system policy through legislation. The results have been remarkable. Not only has the modal share of bicycling trips increased but there have also been improvements in the quality of environment and a reduction in the number of accidents. In Copenhagen, a 50 per cent increase in bicycle trips has been observed in just five years after embarking on a bicycle infrastructure plan showing that the potential for bicycling can be enormous. Figure 1 depicts various German studies (cited by Mathew8) which have estimated the percentage of

---

**Table 1**

<table>
<thead>
<tr>
<th>City</th>
<th>% of bicycle trips</th>
</tr>
</thead>
<tbody>
<tr>
<td>Delft</td>
<td>43</td>
</tr>
<tr>
<td>Groningen</td>
<td>50</td>
</tr>
<tr>
<td>Copenhagen</td>
<td>25</td>
</tr>
<tr>
<td>Delhi</td>
<td>6</td>
</tr>
</tbody>
</table>
total trips that bicycling could achieve. Other studies have concluded that 25 to 35 per cent of all motorized trips could be transferred to bicycles. Studies from New York show that 49 per cent of commuters would bike to work from a distance of 10 miles or less if bike lanes, parking and showering facilities were provided.

The Dutch Bicycle Master Plan has identified three areas in which advances must be made in order to realize the potential of cycling:

- A comprehensive network of cycle routes and facilities are needed.
- Traffic restraint measures are needed.
- Attitudes towards cycling should be positive.

Studies show that building a bicycle network is also economically viable. An economic assessment of a cycle network in Normanton concluded that the total cost of building the bicycle network can be recovered within one to four years which is a very high rate of return for infrastructural projects. In 1977, the Bedford Urban Transport Study showed discounted benefits to the tune of 25,000 pounds in terms of time and accident savings. Similarly, a study of contra-flow cycle lanes in Cambridge estimated a first year rate of return of approximately 400 per cent. A cost-benefit analysis study done for the UK showed that a modal shift to cycling could save around 1.3 to 4.6 million pounds depending on the amount of modal shift.

The Netherlands has been a pioneer in adopting a comprehensive bicycle policy and has implemented bicycle master plans in most cities (i.e., Delft, Houten, etc.) this has resulted in improved mobility and accessibility for all road users, reduction in air and noise pollution and reduced accidents. In 1990, a project group was constituted to create a Bicycle Master Plan policy document. The main objectives of this Bicycle Master Plan are to get at least 30 per cent more kilometres on bicycle by 2010; to get more people on public transport by improving the bicycle/public transport chain and to limit the growth of distances travelled by car to 35 per cent. Such planning efforts initiated by government have already shown remarkable growth in the use of bicycles. Of total trips in Groningen 57 per cent are on bicycles. In Delft, a growth of 6 to 8 per cent in bicycle traffic has taken place after the implementation of the cycle plan.

The cities and countries which were predominantly motorized have seen growth in bicycle traffic after providing suitable infrastructure for bicycling. Table 2 shows the percentage of trips that are made on bicycles for some European countries. A study by CTC (UK) also showed that there was considerable potential for motorized trips to be converted to...

<table>
<thead>
<tr>
<th>Country</th>
<th>% of bicycle trips</th>
</tr>
</thead>
<tbody>
<tr>
<td>Holland</td>
<td>29</td>
</tr>
<tr>
<td>Denmark</td>
<td>18</td>
</tr>
<tr>
<td>West Germany</td>
<td>11</td>
</tr>
</tbody>
</table>

Table 2
Bicycle trips in selected European countries

bicycling. The study showed that an average town might have nearly 76 per cent of the trips carried out by bicycle if the rate of accidents were reduced and 47 per cent in safe towns with flat terrain.\footnote{Werven GV, 'The City of Groningen Experience', in Still More Bikes Behind the Dikes, 1992} However, careful planning and assessment is needed before embarking on a plan to build a bicycle infrastructure. In 1986, the SVT (Netherlands) published Top 20 Myths of Dutch Traffic Engineering in which bicycling facilities were undisputedly on top of the list. Highway authorities unanimously stated that there was insufficient knowledge in this field.

It can be concluded that a high quality bicycling network appears to alter trends: in several Dutch urban and rural areas it has proven to have a curbing effect upon the growth of motor car traffic.

\section*{Review of Existing Road Network and Traffic Flow}

The Delhi Master plan is representative of textbook example of integrated land use and transportation planning. Developed in 1990, the plan has proposed a five tiered system intended to increase densities, develop mixed use centres, and consequently minimize average trip lengths. By some measures, these planning tools have succeeded: Delhi has high population densities and mixed land use patterns, resulting in short trips, many of which are made by walking, non-motorized vehicles, or public transport. Private car ownership is low by international comparisons.\footnote{Delhi Development Authority, Masterplan for Delhi: Perspective 2001, 13–17.}

The city of Delhi is a network of radial and circumferential arterial roads linking neighbourhoods. This is interspersed with elements like parks, natural features, the Yamuna river, the Ridge, nullahs and utilities like railways, power stations, bus stands. The city can be seen as three districts with distinct characteristics:

\section*{The old city}

This region is a very high density development with narrow roads and numerous by-lanes. The lower floors of houses along the lanes and most of the buildings on the main arterials are devoted to commercial activity. The roads are used by cycle rickshaws, cycles and hand carts along with motorized vehicles. In many locations cycle rickshaws are the preferred mode of transport. Distances to be travelled within the old city are small and the fastest way to travel is to walk or to bicycle. This area is a big attractor as well as producer of bicycle traffic.

\section*{Lutyen's Delhi}

This region has very large plots, generously laid out around parks and along 30 m wide tree-lined avenues. The boundary wall of the bungalows has a large set back from the tree-line. The population density of this region is very low and formal commercial activities are located in specific shopping centres.

However, due to the presence of large roundabouts with no facilities for bicycle traffic, crossing roads can be inconvenient and unsafe. The avenues have fast motorized traffic and are used as links to their destinations, like Connaught Place, Central Secretariat. This area was originally designed with separate service roads which were also used by bicyclists. However, over the years, the service lane space has been used for other purposes like parking, security tents, etc. At some places, service lanes display odd signs saying “cycles only”.

At present there are no major origins for bicycle traffic in this area. This may however, change if safe bicycling was possible. In fact, this area has large number of destinations for bicycle traffic.

\section*{The rest of Delhi}

The cross section of the avenues in Lutyen’s Delhi serves as the model for the arterial roads, with one important difference. The space between the tree line and the boundary wall of the properties serves as a service road for the neighbourhood or colony. This change in perception from Lutyen’s Delhi is probably in keeping with the fact that the neighbourhoods...
adjacent to arterials ought to have traffic openings onto arterials only at discrete intervals. Traffic on these service roads is two-way, often fast; entering on or coming off the arterial. A large number of bicycle trips are produced in this area with destinations in this area itself or Lutyen's Delhi or the Walled City.

Each of the three regions have distinct characteristics in terms of traffic composition, physical layout, land use and population densities. Therefore, a very detailed and integrated planning is required to integrate all these three regions and provide smooth and safe transportation of bicyclists from their origin to destination.

Our studies have shown that the curb-side lane (3.5 m) is mainly used by bicycle traffic and other NMVs at present. Motorized traffic finds it difficult to use this lane. However, a bicycle lane requires only 2.5 m. Thus, providing a separate bicycle lane would make more space available for motorized modes. Moreover, most of the major arterials in Delhi have 6.5 m wide service roads. The existing right of way is wide enough to accommodate a bicycle lane without taking away any space from motorized traffic. Figures 2 and 3 show the cross sections proposed by DDA and the alternative cross sections incorporating bicycle tracks for 45 m. Figures 4 and 5 illustrate the standard and proposed road layouts for 60m right of way roads. The DDA cross sections designate the wide service lanes as bicycle tracks. The service road is proposed to be used by bicyclists, pedestrians, service trucks and motorized vehicles entering or exiting driveways. However, bicyclists prefer to use the main carriageway because they find unpredictable traffic and road design difficult to negotiate on service roads. In the absence of traffic calming measures, motorized modes move at very high speeds on service roads, thereby making bicycle travel unsafe. Motorized vehicles coming in and out of driveways cause inconvenience to the bicyclists. This coupled with poor visibility due to
Parked vehicles also jeopardizes their safety. The road surface is not as good as the main carriageway surface. Since bicyclists require smooth road surface for a comfortable ride, they prefer to stay on the main carriageway.

More than 500 km of road in Delhi has 45 m or more than 45 m wide ROW offering an excellent opportunity to design segregated bicycle tracks. It may be possible to introduce segregated bicycle tracks on another 250 km of roads having 30 m wide ROW by reorganizing traffic priorities. Two lanes of 3 m width each can be provided for motorized traffic, an exclusive bicycle lane and at least 6 m wide service lane.

As far as bicycle infrastructure is concerned, there are no special facilities for bicyclists. They have to share the road space with other road users like buses, cars, etc. Our survey results show that a large section of bicycle users do not have access to parking facilities either at home or at workplace.12

Traffic characteristics

A wide variety of vehicle types (including bicycles and human and animal drawn vehicles) share the same road space in Delhi. All modes of traffic use one, two and three lane roads. Delhi traffic laws do not segregate bicycle traffic and enforcement of speed limit is minimal. Motor vehicles (MVs) and non-motorized vehicle (NMVs) have different densities at peak traffic hours at different locations of Delhi.

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. The integration of motorized vehicles (MVs) and non-motorized vehicles (NMVs) has occurred naturally. 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 lane 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.

The average speed of MV at peak hours is much lower than the capacity speeds, but even then the bicyclists are moving at their desirable speed. At peak traffic hours the average speeds of MVs do not vary much between high density and low density sites.\textsuperscript{13}

A study done by us on midblock conflicts gives information regarding the use of road space by different road users. The fourteen sites studied by us show that maximum mixing of NMVs and MVs occurs at the bus stops.\textsuperscript{14}

Their interaction with other MVs is minimal at other locations. Natural segregation takes place on three and two lane roads. In three lane roads, MVs are using two lanes and the curb side lane is being used by NMVs.

Vehicles of one group tend to interact mostly with other vehicles of the same group. This shows that the MVs speed remain low because of MV densities, and because they are not using the curb side lane for passing manoeuvres. Their speed is not affected by interference from NMVs.

Since the MV traffic lane is 3.5 meters wide, it can accommodate flow rates of at least 6000 bicycles per hour.\textsuperscript{15} 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.\textsuperscript{16}

Though the peak volumes are not exceeding saturation capacities, we find the average speed remains in the range of 14 to 39 km/h. On two lane roads the MV flow rates are close to or less than saturation values. It is only on the one lane roads that we find flow rates of 726 bicycles/hr and 616 PCU/hr. Both these values are approximately one third of their respective saturation capacity values for one lane.

These observations indicate that on two and three lane roads, bicycle traffic will always segregate itself into the curb side lane even without any direction for the same. This integration will only take place if the bicycle flow rate exceeds 6000 bicycles per hour for one MV lane or on the other hand if the MV flow rate exceeds one lane capacity on two lane roads and two lane capacity on three lane roads.

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 one whole MV lane gets separated by bicycles irrespective of bicycle density.

Our data reveals 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.\textsuperscript{17}


\textsuperscript{16} Guidelines for Capacity of Urban Roads in Plain Areas, Indian Road Congress, New Delhi, 1990.

\textsuperscript{17} Op.cit. 6.
Unless M V flows deem it necessary, it is more efficient to have one bicycle lane—one M V lane and one bicycle lane—two M V lane instead of two and three M V lanes with non-segregated traffic. Two and three lane roads could have integrated facilities only in business, and shopping areas where mid block sections are short and severe traffic calming techniques are used. In urban business and residential areas with one lane roads, mixed traffic can be allowed, provided M V speeds are regulated and kept below 30 km/h by traffic calming methods.

Travel patterns

Socio economic characteristics along with land use patterns influence mode choice and trip patterns. Distance and travel time to workplace show the combined effect of these two factors.

Modal share

It was observed in a recent study that nearly 44 per cent of individuals walk to fulfill their travel needs in Delhi. Personalized modes of transport are used by 23 per cent individuals (including bicycles). Motorized two wheelers are used by 7 per cent of the population, and 30 per cent of the population uses public transport for their travel needs. It is important to note that although motorized two wheelers M TW form the largest share of registered vehicles, however, their usage is less than cars and buses. High ownership does not necessarily ensure high usage of M TW.

Table 3 shows changing modal share of trips in Delhi. Share of M TW trips shows a significant increase from 1981 and decline in the share of bicycle trips is considerable. Table 4 shows changes in average trip lengths by different modes.

Share of bus trips has shown marginal increase. Again the use of M TW does not reflect a high ownership of M TW.

Despite decline in number of buses on the city routes, share of trips by buses have increased. As it led to more overcrowding in city buses making them less attractive for many people? This trend needs further investigation. This may be contributing to increased M TW trips also, i.e. those who could travel by buses are using the M TW because the bus travel has become more unpleasant.

Similarly, decline in overall share of bicycle trips does not reflect reduced demand for bicycles. In fact, the CRRI study showed that cycle traffic contributes between 13 to 34 of total traffic on roads in traffic volume counts classified according to direction recorded from 6 a.m. to 9 p.m. on a typical week day.

The CRRI study has also shown that cycle traffic has been found to be significantly higher in outer areas and the urban area border as compared to the central and the middle areas. Clearly, cycles are being used for long commutes also.

Network Level Proposal

A well functioning bicycle infrastructure is the key to a longer lasting safe road-traffic system. The bicycle network which is to be
Figure 6
Right of way for masterplan roads

<table>
<thead>
<tr>
<th>right of way</th>
<th>Line</th>
<th>Sum(Length)</th>
</tr>
</thead>
<tbody>
<tr>
<td>30</td>
<td></td>
<td>251.7</td>
</tr>
<tr>
<td>45</td>
<td></td>
<td>232.6</td>
</tr>
<tr>
<td>60</td>
<td></td>
<td>136.4</td>
</tr>
<tr>
<td>80</td>
<td></td>
<td>6.3</td>
</tr>
<tr>
<td>36</td>
<td></td>
<td>52</td>
</tr>
<tr>
<td>90</td>
<td></td>
<td>0.6</td>
</tr>
<tr>
<td>100</td>
<td></td>
<td>0.7</td>
</tr>
<tr>
<td>70</td>
<td></td>
<td>21.8</td>
</tr>
<tr>
<td>75</td>
<td></td>
<td>31.9</td>
</tr>
<tr>
<td>84</td>
<td></td>
<td>1.6</td>
</tr>
<tr>
<td>68</td>
<td></td>
<td>0</td>
</tr>
<tr>
<td>phase</td>
<td>Line</td>
<td>Sum(Length)</td>
</tr>
<tr>
<td>-------</td>
<td>------</td>
<td>-------------</td>
</tr>
<tr>
<td>0</td>
<td></td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td></td>
<td>90.5</td>
</tr>
<tr>
<td>2</td>
<td></td>
<td>275.5</td>
</tr>
<tr>
<td>3</td>
<td></td>
<td>368.6</td>
</tr>
</tbody>
</table>
developed in the city must fulfill three objectives. These objectives are:

- Traffic flow of all vehicles using that corridor should improve
- Number of accidents involving bicyclists should reduce
- Greater use of bicycles should be encouraged.

To reach a good design of a bicycle-infrastructure, an integral approach is needed. This includes the following:

**Network level**

Though a large number of bicycle trips may be short distance journeys, provision has to be made for bicycle trips at a network level. This is required to ensure the smooth functioning of the other modes of transport as well.

**Connecting level**

The system of cycle-routes is part of the total traffic system. Cyclists are not weak road users. They are, however, vulnerable when in confrontation with fast moving traffic. This requires special alertness in many cases. Avoiding conflicts between different types of traffic by separating them becomes a necessary measure sometimes. Solutions can also be investigated in lowering motorized traffic speeds or limiting motorized traffic on important cycle routes.

**Facility level**

Cyclists deserve equal treatment. They should not be given the remaining space in a road design and the left over time in traffic signal control. The quality of facilities offered to cyclists should be measured with the same criteria as the quality offered to other road users. All requirements and wishes of cyclists can be classified under five main heads: 20

- **Coherence:** The cycle-infrastructure forms a coherent unit and links with all departure points and destinations of cyclists.
- **Directness:** The cycling-infrastructure continually offers the cyclists as direct a route as possible (so detours are kept to a minimum).
- **Attractiveness:** The cycling-infrastructure is designed and fitted in the surroundings in such a way that cycling is attractive.
- **Safety:** The cycling-infrastructure guarantees the road safety of cyclists and other road-users.
- **Comfort:** The cycling-infrastructure enables a quick and comfortable flow of bicycle-traffic.

**Levels of the network level proposal**

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

- **Network route planning**
- **Road section planning**
- **Intersection planning**

**Network route planning**

A cycling-network has the shape of a series of links and junctions. It is intended that a network complies with the wishes of bicycle traffic as much as possible. To achieve this, an insight into the pattern of departure points and destinations of cyclists is required.

Detailed origin destination analysis of bicycle users shows that there is a need for a continuous network for bicyclists covering the whole of Delhi. This is because there are no areas where they are not present.

Since majority of the bicyclist at present are captive riders and daily commuters, the proposed network must enable direct and safe bicycle-travel within a coherent system. The proposed routes must guarantee a coherent network structure, minimize trip length (directness) and minimize the number of encounters between cyclists and motor vehicles (safety).

---

Figure 6 (see p.12) shows right of way (ROW) of existing roads in Delhi ranging from 30 m to 90 m. All these roads need to be developed as an integral part of the bicycle network. Routes with the highest (expected) use graduate to the through routes of the plan. Because investment in these routes results in optimum efficiency, particular attention is given to improving the quality of through cycle-route.

Volume does not have to be the only criterion on the basis of which a route is designated an element of the main network. To achieve a recognizable and coherent structure and to avoid discontinuities, means that less intensively-used routes have to be included in the main network. The same considerations apply with the joining of the designed network to the main routes of other cycling-networks, especially on the outskirts of an urban area (transition inside/ outside built up area). The principle of continuity is more important here than that of (limit of) volume.

The development process can be prioritized to meet three objectives of the bicycle masterplan. The bicycle network is to be developed in four phases. Figure 7 (p.13) details the areas covered in each of these phases, which have been outlined as follows:

Phase I: Routes which have heavy bicycle traffic and share the road space with other traffic should be developed in the first phase. This would result in improving the flow of bicycles. The flow of public transport buses and motorised private modes would subsequently improve as their flow is affected by the presence of bicycles on the same carriageway.

Phase II: In the second phase, major arterials which carry fast traffic are to be developed. On these roads bicyclists face a higher risk of being involved in fatal road accidents particularly during non-peak hours, and at night when visibility is poor. 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.

Phase IV: In the fourth phase, bicycle routes are proposed through parks and green belts. This would primarily be additional network capacity for bicyclists.

Traffic Calming

The network developed in the proposed three phases primarily serves the 'connecting' function (through cycle-routes, urban level/inter-regional level); the network which serves the other two important functions:

- to distribute (distributor cycle-routes, district level);
- to access (access cycle-routes, neighbourhood level)

is to be developed on roads which have less than 30 m ROW. If the available space does not permit segregated bicycle track on these roads then traffic calming techniques have to be used to develop a bicycle friendly network.

The current thinking is that roads in cities should be designed such that vehicles are not able to operate at maximum speeds greater than 40–50 km/h. This makes traffic move with less acceleration and deceleration, while average speeds remain around 15–20 km/h. This is called "traffic calming". Experience shows that when traffic calming principles are used in road design, accidents and pollution reduce and neighbourhoods become more livable. Table 5 details some traffic calming measures which can be adopted and the problems it could help resolve.

Figures 8, 9 and 10 illustrate recommended designs for road humps which can be experimented with in India. These designs have been adapted from many of the successful measures already adopted in Europe.

In India, the traffic mix is very different from that in Europe. We have

<table>
<thead>
<tr>
<th>Table 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Some traffic problems and their possible solutions</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Issue</th>
<th>Problems</th>
<th>Solutions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pedestrian crossing at midblocks undivided arterials</td>
<td>Pedestrians have to cross traffic coming from both directions</td>
<td>Pedestrian island provides safe waiting space.</td>
</tr>
<tr>
<td></td>
<td>Many times the gap between vehicles does not permit the crossing of the complete width of the road without stopping</td>
<td></td>
</tr>
<tr>
<td>Pedestrian crossing at T-junction</td>
<td>Vehicles turning at high speed at T-junctions pose danger to pedestrians crossing the road</td>
<td>Raised pedestrian platform acts as a hump.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Divided channelizer controls traffic flow of incoming and outgoing vehicles and provides a safe waiting space in the middle for pedestrians.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Different colours and texture enhances the visibility of the crossing.</td>
</tr>
<tr>
<td>Four-way uncontrolled junction</td>
<td>Conflicts between speeding vehicles coming from different directions</td>
<td>Raised platform with ramps (1:20) on all sides check vehicle speeds.</td>
</tr>
<tr>
<td></td>
<td>Conflicts between speeding vehicles and bicyclists and other slow moving vehicles.</td>
<td>Different colour and texture enhances the visibility of the crossing.</td>
</tr>
<tr>
<td></td>
<td>Unsafe pedestrian crossing</td>
<td>Unsafe pedestrian crossing</td>
</tr>
<tr>
<td></td>
<td>Several round humps (1 meter diameter and 50 mm high at the centre) placed at the crossing will force motorised vehicles including two wheelers to slow down. The gaps between them permits bicyclists to go without difficulty.</td>
<td></td>
</tr>
</tbody>
</table>
a much larger number of bicyclists, rickshaws, human and animal pulled carts and motorised two-wheelers. Therefore, it is very important for us to experiment with these designs and then evolve new designs, which suit our environment better.

**Detailed Design of Selected Routes**

Three traffic corridors were studied in greater detail:21 of these the Preet Vihar to Connaught Place and Wazirabad Bridge to Nand Nagari corridors were surveyed for a detailed physical layout and traffic data. These were then redesigned keeping in mind the broad philosophy of the proposed network system. Since these two corridors were redesigned completely and accurately with site specific solutions given for each conflict encountered, it was imperative to set-up some basic criteria and guidelines for the redesign. For each corridor an individual set of criteria for the cross-sections and junctions were defined. The Preet Vihar to Connaught Place corridor is described in some detail in the following pages.

**Detailed Design Criteria for road development plan to improve the movement of public transport vehicles, bicycles, pedestrians and other modes of transport.**

- Physically segregated bicycle tracks on routes which have > 30 m R.O.W.
- 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
  - Restricted free left turns
  - Modified traffic signal cycle
  - Roadside furniture to ensure safe bicycle movement and minimize interference from motorized two-wheelers.

---

All measures which are needed to bring elements of the main network to the desired level of quality are included in the detailed design of the corridor. Cycle-routes comprise interconnections or road-sections, and intersections. Different types of problems are associated with road-sections and intersections, these are therefore detailed separately. 

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. It would seem logical to prefer separating cyclists and other road-user on through cycle-routes and mixing them on access cycle-routes. However, experience shows that this choice is not so simple. A through cycle-route does not necessarily have to consist of cycle-tracks only. If a through cycle-route runs through a quiet residential street, then separation will not be necessary. The road space determines the amount of separation. The usage by and/or the behaviour of the various road-users is an important starting-point when deciding on the measure of separation. 

For a road-section of a certain type of cycle-route one of the three basic forms of road-section should be developed: 
- road-section with physical separation 
- road-section with visual separation 
- road-section with mixed profile. 

**Table 6**

Summary of the possibilities of separating and mixing at junctions

<table>
<thead>
<tr>
<th>Normal flow of bicycle-traffic on the cycle-route to be considered</th>
<th>Presence of cycle-tracks on the road to be crossed</th>
<th>Normal flow of cycle traffic on the junction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mixed</td>
<td>No-cycle tracks</td>
<td>Mixed</td>
</tr>
<tr>
<td>Mixed</td>
<td>Cycle-tracks</td>
<td>Mixed or cycle-tracks</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Cycle-lanes or recommended lanes</th>
<th>No cycle-tracks</th>
<th>Cycle-lanes or recommended-lanes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cycle-lanes or recommended lanes</td>
<td>Cycle-tracks</td>
<td>Cycle-lanes, recommended-lane or cycle-tracks</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Cycle track(s)</th>
<th>Cycle-tracks</th>
<th>Cycle-track(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cycle track(s)</td>
<td>No-cycle tracks</td>
<td>Cycle-track(s)</td>
</tr>
</tbody>
</table>

* On these junctions cyclists are channeled through (streamed) cycle-tracks and bicycle-crossings if necessary from the point of view of road-safety. 

** At these junctions cyclists are streamed via cycle-lanes and recommended lanes if this is desired from the viewpoint of cyclists' manoeuvre and is permissible from the viewpoint of traffic safety.
### Criteria for locating bus lanes

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Central Bus Lane</th>
<th>Curb-Side Bus Lane</th>
<th>Rationale</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Excessive side-entries for vehicles into service lanes individual plots</td>
<td>Limited access to service lanes or widely spaced entry points into adjoining area</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>
</tr>
<tr>
<td>2.</td>
<td>Closely placed traffic lights for vehicles</td>
<td>Traffic lights at larger intervals</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>
</tr>
<tr>
<td>3.</td>
<td>Low frequency of bus-stops</td>
<td>Higher frequency of bus-stops</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 efficient bus-stops.</td>
</tr>
<tr>
<td>4.</td>
<td>Higher volume of two-wheeler three-wheeler vehicles</td>
<td>Lower volume of two-wheeler and three-wheeler vehicles</td>
<td>High volumes of two-and three-wheeler vehicles interfere with the movement of buses in the curb-side lines especially at 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. The difference in sizes of these vehicles sharing the curb side lane makes it unsafe for smaller vehicles.</td>
</tr>
</tbody>
</table>
Road Development Plan for Vikas Marg

Criteria for redesign of road cross-sections

The redesign of road cross-sections should meet the criteria listed as follows:

- In the criteria set for the site-specific choice between Central and Curbside bus-lanes the corridor has a mixed profile. The stretch of Vikas Marg and I.P. Marg have been redesigned with central bus lane and the rest of the stretch down Sikandra road and Barakhambra road have curb-side bus lanes.
- Two lanes of 3 m each are proposed for the main carriageway in addition to the 3.3 m wide central/curb-side bus-lane. In the case of the central bus lane stretches the two 3.3 m wide lanes combine to form a 6.6 m 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 0.4 m 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 3 m.

Criteria for redesign of crossed junctions and T-junctions

An intersection has the highest level of ambiguity in terms of the expected directional split. 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 then should be warned that they are expected to slow down.

All these strategies are implemented through ground design. 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 lane 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: 7.5 m with a sloped leeway of 1.5 m for larger vehicles, (b) In case of buses turning left: 14 m. with a sloped leeway of 1.5 m. 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 traffic stops before the stop line (5 m before the junction), the cyclists have a demarked 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 13 gives these details.

**Intersection with Central Bus Lane**

- Three lanes—straight, left- 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 4.5 m. wide to allow for necessary leeway. The central bus stretch becomes three-lane wide before the junction to allow for a left-turning lane.
- The bus lanes before and after the junction are streamlined.
- The minimum left turning radius according to which the curve of the intersection is plotted is 7.5 m with a sloped leeway of 1.5 m 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 traffic 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 (see Figure 14).
Criteria for redesign of roundabouts

On the Preet Vihar to Connaught Place stretch there is a roundabout junction in the Mandi House area. The roundabout is redesigned to give right of way to cyclists and pedestrian who normally find it very difficult to cross this junction (see Figure 15).

• 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.

• The elevated track, when it crosses the main carriageway, serves as a speed-breaking hump for vehicular traffic; slowing vehicular traffic down as they enter and exit the ring.

Criteria for locating bus stops

• Interchange should be close to their users. Bus and paratransit stops should be near residences in order to minimize walking distance, and major interchanges should have direct pedestrian links segregated from motorised traffic.

• Public transport routes should generally follow main traffic routes. Boarding points should be adjacent to intersections and linked with other parts of the general traffic network particularly footpaths. Measures should be taken to remove cyclists from the main carriageway as they prevent 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, e.g. 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, 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.

• Walkable distance in each direction can be reduced to as low as 50m by removing all free left turns and placing the bus stops after the crossing (in each direction of traffic ROW).
**Future Plan of Action**

The team involved in this project has studied the international literature available on bicycle friendly infrastructure. The detailed design solutions for Vikas Marg Corridor (discussed in the previous section) and Wazirabad corridor have been proposed on the principles derived from international literature. However the Bicycle Master Plan which includes design solutions is an evolutionary process which should influence the road development plan of the city. As part of this evolutionary process we propose a second phase of the study. The second phase will include the following activities:

- **Implementation of the proposed designs**
  The implementation of proposed designs is to be coordinated with NDMC, DDA and MCD. The IIT team will work in close cooperation with the implementing agency to prepare detailed designs required at the time of implementation. The Vikas Marg corridor may be chosen for this purpose. Detailed cost estimates should also be prepared by the implementing agency for straight sections and typical intersections which includes the changes proposed in the new designs.

- **Pilot project experiments using movable furniture on the road**
  These experiments will be conducted to understand the effect of:
  - Closing free left turn movements of vehicles.
  - Providing right turning bay for right turning vehicles.
  - Alternate roundabout designs to streamline traffic.
  - Traffic calming features at the junction of minor-major road
  - Experimenting with central bus lanes and location of bus stops
  Results of the pilot projects will be used to prepare quantitative measures of effectiveness.

- **Workshops to disseminate, discuss and modify the proposed designs**
  IIT organized a round table discussion on creating safe environment for bicycles in the 4th World Injury Conference in May 1998 in Amsterdam and Regional Workshop as a preparation for Velo-Mondiale 2000 in December 1998. In addition to these, two national workshops will be organized to discuss the designs suitable for Indian cities.

- **Preparation of design manual for bicycle infrastructure**
  The manual will be prepared to meet the demand of city planing and implementing agencies like DDA, MCD, etc. The manual will be prepared in close collaboration with a group experienced in preparing such manuals.

- **Preparation of bicycle network in residential neighborhoods**
  Detailed designs will be prepared for selected neighbourhoods to create bicycle friendly environment in the neighbourhood. This will include primarily use of traffic calming techniques and road space management for rationalizing parking.

- **Evaluation of bicycle corridors**
  After the completion of the first pilot corridor a careful evaluation should be carried out to document various positive and negative aspects of the project. Subsequent designs should be modified to improve the performance of all modes of traffic.

**Existing road space can be redesigned for better utilization**
Transportation Research and Injury Prevention Programme
(TRIPP)

TRIPP (Transportation Research and Injury Prevention Programme) is an interdisciplinary programme at the Indian Institute of Technology Delhi. TRIPP focuses on urban and intercity transportation issues as its primary activity. The attempt is to integrate road transport with other modes to plan for optimal mobility with safety, pollution abatement and energy conservation. The TRIPP faculty works on applied research projects, conducts special short term courses, workshops and conferences, guides projects of B Tech, M Tech and Ph D students in collaboration with associated departments and centres. TRIPP serves as a resource centre for transportation related information.