

Sustainable Transport Systems: Linkages Between Environmental Issues, Public Transport, Non-Motorised Transport and Safety¹

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INTRODUCTION

A sustainable transport system must provide mobility and accessibility to all urban residents in a safe and environment friendly mode of transport. This is a complex and difficult task when the needs and demands of people belonging to different income groups are not only different but also often conflicting. For example, if a large proportion of the population can not afford to use motorised transport - private vehicles or public buses - then they have to either walk or ride bicycles to work. Provision of safe infrastructure for bicyclists and pedestrians may need segregation of road space for bicyclists and pedestrians from motorised traffic or reduction in speeds of vehicles. Both measures could result in restricting mobility of car users.

Similarly, measures to reduce pollution may at times conflict with those needed for reduction in road accidents. For example, increases in average vehicle speeds may reduce emissions but they can result in an increase in accident rates. But, most public discussions and government policy documents dealing with transportation and health focus only on air pollution as the main concern. This is because air pollution is generally visible and its deleterious effects are palpable. It is easy for most people to connect the associations between quality of motor vehicles, exhaust fumes and increased morbidity due to pollution. But most individuals are not able to understand the complex interaction of factors associated with road accidents. Health problems due to pollution are seen as worthy of public action whereas those due to injury and death in accidents as due to individual mistakes. Therefore, policy documents dealing with sustainable development for cities always include options for pollution reduction but rarely for accident control.

In this paper we discuss some of the issues concerning public transport, safety and the environment. We illustrate that unless the needs of non-motorised modes of traffic are met it will be almost impossible to design any sustainable transportation system for urban areas. We show that pedestrians, bicyclists and nonmotorised *rickshas* 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. However, it is possible to redesign the existing roads to provide a safer and more convenient environment for non-motorised modes. This also results in improved efficiency of public transport vehicles and enhanced capacity of the corridor when measured in number of passengers transported per hour per lane.

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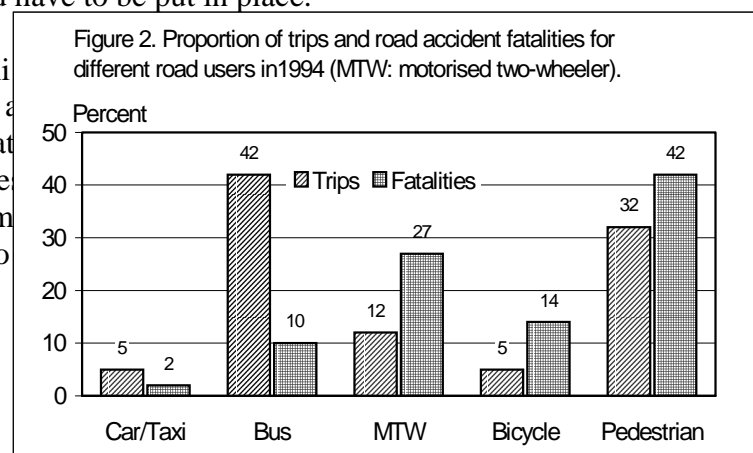
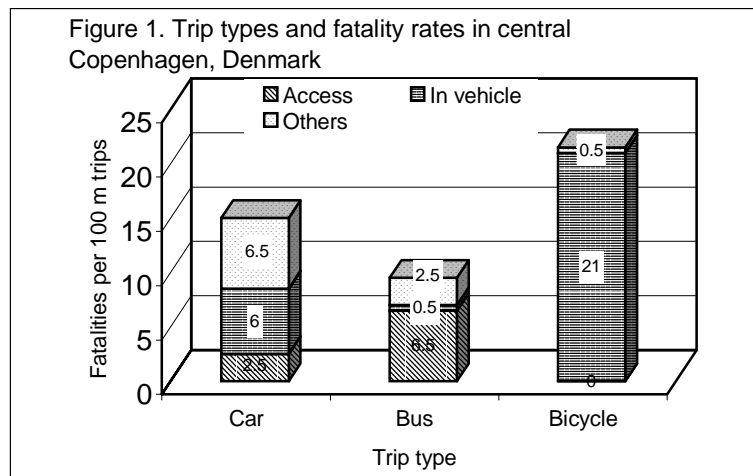
SAFETY AND PUBLIC TRANSPORT

Decisions regarding mode of transport by individuals are based on economic criteria, trip time involved, convenience, comfort and safety. Of all these concerns the one involving safety is the most difficult one for the individual. An important dimension in the perception of benefits of mobility versus perception of accident risk is that the road user's perception of time saved by driving faster exceeds that in reality.¹ The increased mobility is distributed among many road users, usually realised in very small units of a few seconds. The safety benefit is sustained by a relatively smaller number of people who save many years of life (from premature death). An important issue involving transportation strategies aimed at increasing speeds of motorised vehicles is that pedestrians and other non-motorised road users who do not benefit from increased mobility sustain the increased accident risk. Thus the benefits accrue to one sub group, while the disbenefits are imposed on another. This has an important bearing on planning for public transport as all commuters have to operate as pedestrians also and their safety on the roads has to be ensured.

Calculation of risk per trip or over a period of time is very difficult. There are very few studies available that evaluate risk over a whole trip. Jorgensen² has reported the results of a study where injury rates and fatality rates for different trip types were calculated for commuters in Copenhagen, Denmark. Figure 1 shows the results for fatality rates per million trips for different trip types in the central area of Copenhagen. The rates for the traveller are calculated separately for each portion of the trip: access to and from the vehicle and as occupant of the vehicle. In addition, the rate for others killed by the vehicle is also shown. The data show that the risk for an occupant of a bus (0.5) is much less than that for the occupant of a car (6). However, the traveller is subjected to a much higher risk walking to or from the bus (6.5) than that associated with the car (2.5). This is probably because bus users have to walk longer distances than those using cars. Overall, car and bus users seem

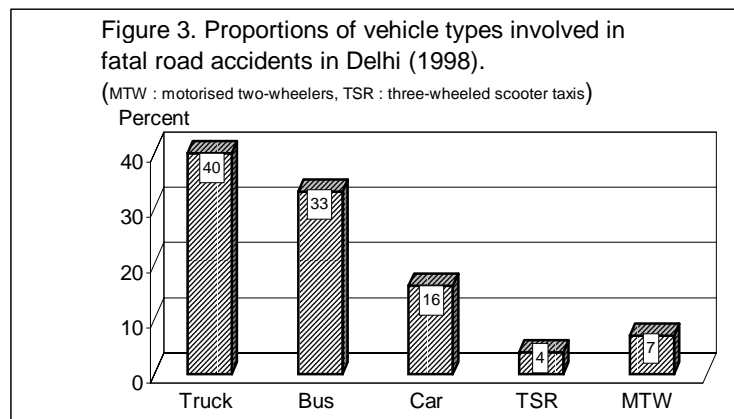
to have a similar risk in central Copenhagen. However, the bus seems to be involved in fewer fatalities with other road users than the car. The bicycle users have the highest risk per trip; almost three times that of the bus and car users. These ratios would change if the modal shares and vehicle speeds were different in Copenhagen. It would be fair to expect personal vehicle users to use public transport only if the safety of pedestrians could be ensured. Similarly, to make bicycling more popular in Copenhagen, bicycle facilities and traffic management policies for bicyclists' safety would have to be put in place.

Such detailed data for Delhi made by different modes in Delhi³ and These data show that the ratio of fatalities to the lowest for buses. There are no fatalities or the bus. We can assume that some bus commuters and only a few who



included in the statistics the proportion of bus commuters getting killed would be more than the 10% shown in Figure 2. It should be noted that a large proportion of the bus commuters are killed and injured in the process of entering or leaving the bus or when they fall off a moving bus as there are no doors on public buses in Delhi. These injuries and fatalities are frequently reported in the newspapers. The higher risk associated with bus travel must be acting as a deterrent for private vehicle owners to use public transport. At present 62% of all motorised trips in Delhi are made by buses. This share is likely to decrease with increase in incomes. If this share is to be maintained at present levels, then the safety of commuters as bus users, bicyclists and pedestrians would have to be improved.

Figure 3 shows the proportion of vehicles involved in road accident fatalities in Delhi. These data show that buses were involved in 33% of the fatal crashes in Delhi in 1998.⁵ These proportions are very different from those experienced in large cities in highly industrialised countries (HIC). For example, data from New York City show that in 1994 buses were involved in only 4% of fatal pedestrian accidents and there were no other fatal accidents with bus involvement.⁶ These differences between New York City and Delhi are probably owing to: lower operating speeds of buses, doors on buses, better pedestrian facilities and lower exposure of non-motorised road users in New



York. These data clearly indicate that if public transport use has to be promoted in mega-cities like Delhi in less industrialised countries (LIC) much more attention has to be given to the improvement in safety levels of bus commuters and the non-motorised transport segment of the road users. This is particularly important because promotion of public transport use can also result in an increase in the number of pedestrians and bicycle users on city streets. Unless people actually perceive that they are not inconvenienced or exposed to greater risks as bicyclists, pedestrians and bus commuters it will be difficult to reduce private vehicle use. However, in LIC cities non-motorised modes of transport already constitute a significant proportion of all trips. It will be difficult to increase this share of public transport and nonmotorised modes unless these modes are made much more convenient and safer. In addition disincentives for using private vehicles would also have to be introduced.

DEMAND FOR BICYCLES/NONMOTORISED VEHICLES IN DELHI

Bicyclists constitute an estimated 7 percent of all trips made by mechanical modes of transport.² This amounts to one million bicycle trips a day in a city of 9 million persons and 2.7 million motorised vehicles. Official statistics show that the share of bicycle trips of the total trips has declined from 17% in 1981 to 7% in 1994, however, it is not certain that absolute number of bicyclists has reduced.² A large number of commuters are still using bicycles and other non-motorised modes of transport. Low-income residents living on the outskirts of the city also commute across the city to distant work centres and in search of employment. Unlike the traffic in high income countries, bicycles and other non-motorised vehicles are present in significant numbers on the arterial roads and inter-city highways designed for fast moving uninterrupted flow of motorised vehicles.

At present even a subsidised public transportation system is cost prohibitive for a significant segment of the Delhi population. If we assume a minimum of 4 trips per household per day at a cost of Rs. 4.00 per trip (US \$ 1 = IND Rs. 40) for public transportation, a household would need to spend a minimum of Rs. 320 per month for twenty working days. For low income people living on the outskirts of the city, the cost per trip may be Rs.8 to Rs.10 depending on the number of transfers. On an average, a household cannot spend more than 10% of its disposable income on transportation. This implies that the household monthly income must be at least Rs.3200/- for use of the public transport system at minimum rates. According to ORG 1994 survey, approximately 28% of the households in Delhi have a monthly income of less than Rs.2000/-. Another way of calculating the capacity of families to spend on transportation is to base it on the current per capita income. At current prices the annual per-capita income in India is Rs. 14,400. This works out to Rs. 6,000 per month for a family of five persons. Owing to the skewed income distribution in India, the 65th percentile of the population earns the average income. For 100 trips a month per family the family would have Rs. 6 per trip. In Delhi this amount would be greater because of higher income levels. However, 65% of the population would have less money available for transportation. For these people, bicycles or walking is the only logical choice.

In Delhi, 57% of the total trips are less than 5 km. This means 4.5 million daily trips are less than 5 km. Thirty percent of bus trips, 44% of scooter/motorcycle trips and 60% of all three wheeler taxi trips have lengths of less than 5 km. Even if 5% of these trips are converted to bicycle trips, it means 1.1 million additional trips. This would not only lead to substantial savings in fuel but also drastically reduce air and noise pollution. This shift may create capacity for transfer of motorcycle/scooter or car passengers to buses.

In addition to bicycles, non-motorised *rickshas* are used for delivery of goods like furniture, refrigerators, washing machines etc. Semi-skilled workers, carpenters, masons, plumbers, postmen, and courier services use bicycles. Therefore, the demand for bicycles and *rickshas* exists in large numbers at present and is likely to exist in the future also. This situation is not explicitly recognised in policy documents and very little attention is given to improving the facilities for non-motorised modes.

BICYCLES, BUS LANES AND EFFICIENT TRAFFIC FLOW

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 the one, two and three lane roads all over Delhi. Delhi traffic laws do not segregate non-motorised and motorised modes and enforcement of speed limits is very limited. Motor vehicles (MVs) and non-motorised vehicles (NMVs) have different densities at peak traffic hours at different locations of Delhi.

A study of mid-block conflicts in Delhi gives information regarding the use of road space by different road users.⁷ The fourteen sites studied show that maximum mixing of NMVs and MVs occurs at bus stops. Their interaction with other MVs is minimal at other locations. Natural segregation of slow and fast traffic takes place on three and two laned roads. On three lane roads, MVs use the two right lanes and the curbside lane is used almost exclusively by NMVs (traffic in India drives on the left of the road).

Since the MV traffic lane is 3.5 meters wide, it can accommodate flow rates of at least 6000 bicycles per hour.⁸ 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.⁹ Though the peak volumes do not exceed 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 curbside lane even without any direction for the same. Integration of MV and NMV traffic 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 conflicts 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 used by bicycles and other NMVs irrespective of bicycle density.

Since primarily bicycles and other NMVs use the left most lane of the road, buses are unable to use the designated bus lanes and are forced to stop in the middle lane at bus stops. All modes of transport move in sub-optimal conditions in the absence of facilities for NMVs. This disrupts the smooth flow of traffic in all lanes and makes bicycling more hazardous. Therefore, providing a separate bicycle track would make more space available for motorised modes and make bicycling less hazardous. It is also obvious that in the absence of segregated NMV lanes on arterial roads, it is not possible to provide designated lanes for buses.

CONFLICTS BETWEEN SAFETY AND ENVIRONMENTAL ISSUES

The above discussion demonstrates that:

- ◆ Non-motorised modes of transport constitute a significant proportion of all trips made in Delhi and are likely to do so in the future.
- ◆ Increase in use of public transport also results in an increase in walking/bicycling trips
- ◆ At present pedestrians and bicyclists have a much higher risk per trip of being involved in an accident than those using cars.
- ◆ It is not possible to have efficient bus transport systems with designated lanes for buses unless segregated lanes are provided for non-motorised transport.

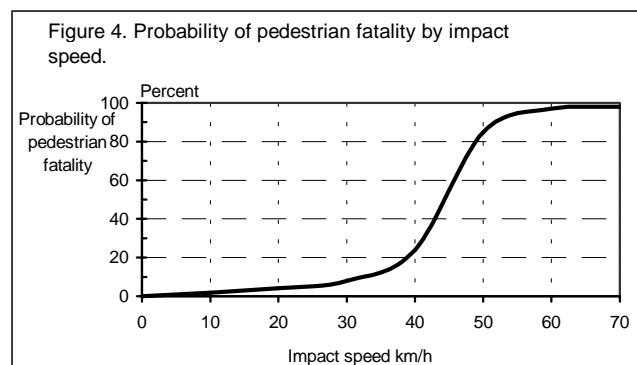
Sustainable transportation options rely heavily on promotion of public transport and non-motorised modes. However, the actual policies promoted do not recognise the conflicts inherent in some of the measures suggested. The Government of India in 1997 prepared a *White Paper* on pollution in Delhi.¹⁰ Subsequently an Environmental Pollution Control Authority was set up for the city. Some of the measures suggested for reducing vehicular pollution are given below:

- Construction of expressways and grade separated intersections.
- Introduction of one way streets and introduction of synchronised signals and area traffic control systems.
- Construction of a metro rail transport system.
- Phasing out of older buses and increase in number of buses.

Effect of expressways, wide roads and grade separated junctions

Construction of expressways through or around cities and grade separated junctions may encourage higher speeds, greater use of private vehicles and longer trip lengths. Higher speeds always result in an increase in the incidence and severity of accidents unless very special countermeasures are put in place for control of injuries. Figure 4 shows the relationship between impact speed and probability of death for a pedestrian.¹¹

These data show that an S-shaped curve describes the relationship between car impact speed and probability of death for a pedestrian. This probability of death starts increasing dramatically at speeds greater than 30 km/h and flattens out at levels above 95% at 60 km/h. A similar relationship would be true for bicyclists and motorcyclists.



Chawla et al report that in impacts with heavy vehicles severe injuries can be sustained even at velocities lower than 30 km/h.¹² Thus very small increases in speeds can

result in large increases in deaths and injuries. This increase in risk has the maximum effect on pedestrians and bicyclists resulting in lower use rates of public transport services.

Wide roads and expressways (especially elevated sections) and grade separated junctions also divide the urban landscape into separate zones. It becomes very difficult for people to cross these arteries on foot or using other non-motorised modes. As explained above, this has the effect of discouraging public transport use, as all commuters using buses have to cross the road at least two times for every round trip at the origin or the destination. Elevated roads also reduce the attractiveness of business and entertainment activity in their vicinity.

Grade separated junctions have a similar effect. The area occupied by grade separated intersections is much greater than ordinary intersections. The location of bus stops at grade separated intersections is such that commuters have to walk greater distances for changing bus routes. This can discourage those who own private means of motorised transport from using public transportation modes. In addition, because of the increase in walking distance and road widths, pedestrians and commuters would be exposed to higher accident risks. This would further discourage use of public transportation by children, disabled persons and other vulnerable road users.

A grade separated intersection inside the city speeds up traffic at that junction and the arrival rate of vehicles at the next light controlled junction increases. This causes greater delays at junctions on both sides, especially during rush hours. Therefore, it is not clear whether such junctions serve a useful function over a network in terms of travel time or reduction in pollution. At grade separated junctions noise and exhaust is produced at a greater height and spreads over a wider area. This makes this area unsuitable for living and other community functions.

This is very well illustrated by the environmental impact assessment done for the construction of the inner ring road in Guangzhou, China.¹³ This inner ring road is a "modern high-speed road running around the centre of the city" with a total length of 26.7 km. Elevated sections account for 75.8% of the length with design speed of 60km/h. The funds invested for construction were loaned by the World Bank. A detailed environmental protection and monitoring plan has been worked out for this project. Some of the important guidelines are outlined below:

- Increase distances between residential houses, sensitive areas and the ring road.
- Minimum distance between road and buildings 20 m.
- First row of buildings not suitable for schools, hospitals etc. These should not be within 100m of the road.
- Buildings sensitive to vibrations not to be within 40m of the road.
- Strict controls of heavy vehicle use at night to prevent noise pollution.
- Strict control of speeding by all vehicles to limit noise.
- Elevated roads should be reduced as far as possible, and double-layer or multi-layer roads should not be adopted.

This shows that any high capacity road inside a city influences land use around it and makes it less people friendly. Owners of residential houses also tend to shift away from such locations. The experience of large cities in China shows that construction of such high capacity roads has not even improved traffic congestion levels:

Guangzhou: Has an orbital expressway and inner ring road and a large number of interchanges. The total number of vehicles is 1 million. However, the average speed on north-south and east-west main roads for 12 hrs in daytime is 18-21 km/h.¹²

Beijing: Has constructed two ring roads and the third ring road is in the process of completion. The city has already constructed 119 flyovers and 202 overpasses. The total number of vehicles is 1.2 million. However, the rush hour average speed on trunk roads is still 13-19 km/h.¹⁴

Shanghai: The road area in Shanghai has been increased by 42% between 1991 and 1997 and 400 roads have been designated as one-way streets. The total number of vehicles is 1.3 million. The average vehicular speeds inside the inner ring road during rush hours are 16 km/h.¹⁵

Shenzhen: The city has completed construction of 139 km of highways, the total number of vehicles is 250,000, but the rush hour average speed on main roads is 20 km/h.¹⁶

It is probably this experience of developments in Chinese cities that prompts Wu (Ministry of Construction) and Li (China Academy of Urban Planning and Design) to comment that "*In the past five years, the input to road infrastructure in the large cities has been doubled. Almost all the large city authorities believe that the situation of traffic congestion may be alleviated through road construction.... But to date, we are still short of rational study which verifies the relationship between road infrastructure and traffic volume or the ownership of motor vehicles.... The traffic volume introduced with road construction may again increase vehicle emission and cause new traffic congestion, multiplying all the pollutants. So there would be no direct cause-and-effect relationship among infrastructure construction, pollution prevention and environmental protection*" (emphasis added).¹⁷

Wu and Li's data show that though the number of public transit vehicles increased in all of the 12 large cities studied in China between 1993 and 1997, the total number of passengers using public transport decreased in 8 of them. Bicycle use has also reduced in cities like Beijing, Shanghai, Shenzhen, Zhuhai, Xiamen and Guangzhou. This could be because bicycle use is being restricted on the major roads in some of these cities in order to promote "smoother" motor-vehicle movement. This decrease in public transport use can be the unintended effect of the building of high capacity roads in the city which increase risk to pedestrians and bicycle users and encourage private motor vehicle use.

A study on relationships between road capacity and induced vehicle travel by Noland concludes that induced travel demand is a likely outcome of capacity expansion and that over time, the induced demand effect becomes somewhat more important, relative to other factors affecting growth.¹⁸ This is particularly true for urban areas. Similar views are expressed in a report from UK prepared by the Standing Advisory Committee on Trunk Road Assessment (SACTRA).¹⁹ The Committee found that "induced traffic can and does occur, probably quite extensively, though its size and significance is likely to vary widely in different circumstances." The SACTRA report found that induced traffic is of 'greatest importance'

under certain circumstances. These include "where trips are suppressed by congestion and then released when the network is improved". The report clarified that "in urban areas where there are many alternative destinations, modes and activities, induced traffic may be an appreciable consequence of major road building schemes... It will simply not be possible to cater for future, unrestrained demand for travel by private vehicles. Demand management measures and public transport policies are likely to form part of an overall transport strategy aimed at containing the demand for travel by road within the capacity of the road system."

An analysis of the relationship between highway expansion and congestion in metropolitan areas based on the 15-Year Texas Transportation Institute (TTI) in the U.S.A. shows similar results. Analysis of TTI's data for 70 metro areas over 15 years, shows that metro areas that invested heavily in road capacity expansion fared no better in easing congestion than metro areas that did not. Trends in congestion show that areas that exhibited greater growth in lane capacity spent roughly \$22 billion more on road construction than those that didn't, yet ended up with slightly higher congestion costs per person, wasted fuel, and travel delay.²⁰

These experiences from very different locations suggest that construction of more high capacity roads can have the unintended effect of reductions in public transport and bicycle use without increasing vehicle speeds or reducing congestion on city roads. Reductions in bus and bicycle use would result in higher pollution levels and possible increase in traffic congestion. No detailed studies have been done to understand the effect of these changes on road user behaviour in cities of low-income countries. It is possible that in these countries the construction of high capacity roads at the expense of facilities for public transport and non-motorised traffic may make things worse for every one. These effects could include higher incidence of congestion for motorised traffic, higher accident risk for non-motorised traffic and reductions in public transport and non-motorised traffic.

Effect of one way streets and area traffic control systems

The proposals for streamlining traffic by the introduction of area traffic control systems and one way streets must be reviewed very carefully. Area traffic control systems have been introduced in Guangzhou and Beijing but there is no clear evidence regarding the alleviation of congestion. An international review of the performance of advanced traffic control systems (ATCS) concludes that "ATCS may have shown promising results in computer simulations under controlled environment but they have failed to produce results under actual traffic conditions. The heterogeneous nature of traffic in Indian cities is not modelled in the existing ATCS and therefore, their success is highly suspect."²¹ The evaluations done in Canada, U. K. and U. S. A. show improvements in overall traffic flow of 2%-10% in some cases and a degrading by 2% - 12% during peak hours in others.

One of the reasons why ATCS do not improve traffic flow conditions during peak hours is that the sensors in the roads are saturated most of the time and so the lights function on a fixed time mode. If there is a continuous arrival of vehicles at all limbs of the intersection then the sensors cannot give priority to any group. In central business districts of large cities most major intersections would not have any limb where there are no vehicles waiting for a green signal. Since the detectors would be placed over 4-6 car lengths they would be saturated most of the time. Therefore, ATCS would improve traffic flow only during off-peak hours and on those intersections where there is very little traffic flow in one direction. Typically 30-40 of the busiest intersections are selected for introduction of ATCS in megacities of Asia. As

explained above, these are precisely the locations where the ATCS would not function any better than properly programmed fixed time traffic light controllers. In any case, the number of intersections selected typically comprise less than 10% of the total number of intersections in a megacity. This does not really help solve the problem of congestion and pollution significantly. It would be much more cost effective to install well programmed fixed time traffic light controllers rather than wasting resources on ATCS. However, when traffic lights are co-ordinated for smooth traffic flow, care has to be taken that road users are not encouraged to increase speeds over 50 km/h on arterial roads. If this is not done there is a possibility of increase in the number of accidents.

Introduction of one way streets should be done only when absolutely necessary. One way streets have the effect of increasing travel distances and hence fuel consumption as people cannot use the shortest routes between origin and destination. Influence of one way streets on induced demand for motorised travel is also not studied in detail. The city of Shanghai has made 400 streets one way, but the congestion levels remain high.¹⁴ If bicycle riders are also forced to obey the one way regulations then it would discourage bicycle use because of increase in trip lengths. When one way streets are designed special care has to be taken that free turns are not allowed, otherwise it becomes impossible for pedestrians to find a safe period to cross the road. On 4 and 6 lane one way roads it would be essential to provide pedestrian refuges in the centre of the road at intersections to ensure safety.

Metro rail systems

Construction of metro rail systems is considered an important counter measure for reduction in congestion and pollution. Almost all megacities in Asia have plans to construct such systems. However, the cost effectiveness of such projects in low-income countries is very doubtful. Two major studies done to understand the performance of metro rail systems by the World Bank and the Transport Research Laboratory (U.K.) make the following conclusions:

- *It is difficult to establish the impact of metros on traffic congestion, in isolation from other factors. However, there appears to be impact in 10 of the 12 cities for which information exists. In one of the remaining two, Sao Paulo, the impact was short lived, while time will tell whether this is also the case in Manila. The general conclusion is that contrary to expectations metros do not appear to reduce traffic congestion. The passengers are mostly captured from the buses, but the reduction in bus traffic is not proportional and represents only a small part of the total traffic. The relief to traffic congestion is short lived because private traffic rapidly grows to utilise the released road capacity. There has been very little shift from car use... In most cities in most developing countries it will not be possible to justify metros rationally... In these cities we have sought to direct attention to their priorities and actions to improve the bus and paratransit system which will result in achievable improvements.²²*
- *Several developed countries have industries for metro systems facing lack of demand at home. Part of their foreign policy is to make soft loans to support these industries. At the same time in the developing countries governments are interested because, (1) a large construction project will bring jobs, (2) a metro system seems modern, and (3) because the cost will not be borne until the project has been built; even then the financing may be about 3 percent. A reason not to invest, financial discipline is often not regarded as important. There was money to be made, prestige and political power to be won... Short*

*term and long term motivations lay behind the construction of the metro. Firstly, there was the desire to immediately improve political fortunes. In the longer term there was a desire to build a monument to those holding office at that time.*²³

The experience from Chinese cities supports the conclusions that building metro systems does not necessarily reduce congestion and decrease private transport use. The metro system in Beijing takes only 11% of the public passenger transport volume and a report from Beijing states that "As the advanced track transport system is enormously expensive and requires long construction period, it cannot be taken as immediate solution".¹³ Shanghai has built a 22.4 km metro line which carries only 1% of the total number of passengers in the city.¹⁴ The number of public transit vehicle equivalents increased by 91% between 1993 and 1997 but the total number of passengers carried decreased by 53% in the same period.¹⁶ Guangzhou has finished construction of a metro line but details of change in surface traffic are not available. The city has increased availability of public transport standard vehicle equivalents by 97% but total number of passengers carried has increased by 62% only.¹⁶ In light of this experience Wu and Li conclude:

*"Although the central government is actively promoting the Chinese built underground carriages and equipment, the cost of construction and operation for metro is still too high to bear for most cities. Urban rail transport is vital to the megacities like Beijing, Shanghai, Guangzhou and Tianjin. But for other cities or even the outer areas of the upper mentioned cities, alternatives should be considered including bus-only lanes, improved trams, elevated or ground rails and suburban rails...As a matter of fact, the already built metros in some cities have not become a means of commuter for the middle or low income class...The practice in developed countries show that the development of public and rail transport itself does not necessarily block the process of motorisation or reduce the number of motor vehicles. Nor does it alleviate traffic congestion. Thus it cannot fundamentally improve traffic contamination."*¹⁶

Construction of a metro rail system and increase in number of buses would also increase the number of access trips by walking and bicycling. High-density metro corridors increase the presence of pedestrians on the surface. This can result in higher accident rates if special measures for traffic calming, speed reduction, and provision of better facilities for bicycles and pedestrians were not put in place in parallel. Therefore, there is no evidence that the construction of a metro rail system on its own would result in the reduction of congestion, pollution or road accidents. It is important the alternative lower cost methods of transportation be explored much more seriously.

The experience of designing and running a high capacity bus system in the city of Curitiba in Brazil gives us a very good example of what is possible in planning public transportation systems at a fraction of the cost (5%-10%) involved for metro lines.²⁴ Special bus and bus stop designs have been developed in Curitiba to make access to buses easier, safer and faster. This is combined with provision of segregated bus lanes where necessary, traffic light priority for buses and moving buses in platoons. A specially designed bus system of this sort can carry up to 25,000 - 30,000 passengers in one hour in each direction. Since such systems can be put in place at a fraction of the cost of metro systems without digging or building elevated sections, they can be introduced on all major corridors of a city. Since the total number of lines so built would be many more than the high cost metro system, the total capacity of this system would also exceed that of a limited metro rail network. An intelligent mix of electric trolley buses and other buses running on diesel and alternate cleaner fuels

could take care of pollution issues. The availability of modern computer networks, communication systems and intelligent transport technology hold great promise for making high capacity bus systems even more efficient and user friendly. Even the highly industrialised countries did not have these options available to them in the past decades and so very little serious research and development work has been done to optimise designs for megacities in low-income countries. Any investment in this direction should be highly profitable.

Phasing out of older buses

Phasing out of older buses can result in higher operating expenses and increase in user costs. A study from Delhi shows that 3% of the city bus service passengers own cars and 18% own scooters and motorcycles.²⁵ About 11% of the bus users in Delhi travel by private chartered buses that assure them of a sitting place in return for monthly contract tickets. These bus users are on an average have higher incomes than those using the city bus service and 11% of them own cars and 44% own motorcycles and scooters. At present the average cost for these commuters is about Rupees 7 (US\$ 0.18) per trip. This cost is close to the marginal cost of running a motorcycle for 10 km. Therefore, it is possible that an increase in fare prices might result in many commuters reverting to use of personal modes. This would be particularly true for those who own scooters and motorcycles, as the running cost for these vehicles is relatively low. Higher use of these vehicles can offset the environmental advantage of using less polluting buses. Figure 2 shows that use of motorised two-wheelers have a very high risk of accidents associated with them. It is possible that phasing out of older buses or increasing the cost of buses due to other reasons can result in increased pollution and accident rates unless the willingness of commuters to pay higher costs is carefully analysed. Such policies may be successful only if bus use costs remain reasonable and the use of personal vehicles is perceived to be very inconvenient. If the cost of cleaner buses is found to be such that the fare, which can be recovered from passengers, is not adequate for running the bus system, then methods have to be found for raising adequate funds from the population of the city concerned.

Pollution control strategies cannot be successful in isolation and can have unintended effects in worsening the health of people by an increase in injuries and deaths. When these policies do not result in an appreciable environmental benefit there can be an overall deterioration in health indices. Technological solutions based on improving fuels, engines and vehicles must be accompanied by improvements in road cross sections and providing segregated facilities for non-motorised transport. The next section gives a summary of a plan prepared for Delhi for providing segregated bicycle lanes and designated bus ways on all arterial roads of the city.

PLANNING FOR BICYCLES AND NOMOTORISED VEHICLES IN DELHI

A detailed study completed in Delhi, India, shows how existing roads can be redesigned within the given right of way (ROW) to provide for an exclusive lane for NMT modes (bicycles and three wheeled *rickshaws*).²⁶ The bicycle/non-motorised vehicle plan has been developed for Delhi to fulfill 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.

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

1. Network route planning
2. Road section planning
3. Intersection planning

1. *Network route planning*

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 a majority of the bicyclists are captive riders who are daily commuters (with no other mode choice owing to economic compulsions) the proposed network must enable direct and safe bicycle-travel within a coherent system. The proposed routes must guarantee minimum trip lengths (directness) and minimise the number of encounters between cyclists and motor-vehicles (safety).

The ROW of existing arterial roads in Delhi ranges 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. But 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 recognisable 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 prioritised to meet the three objectives of the bicycle master plan. The bicycle network should be developed in the following phases:

Phase I: The routes which have heavy bicycle traffic sharing the road space with other traffic 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. This will cover 90 km of road length.

Phase II: Routes which should be developed in the second phase are the major arterials which carry MV traffic at speeds of 50 km/h but were not included in Phase I. In non-peak hours and at night when the visibility is poor, bicyclists are exposed to a high risk of 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. The network length covered in this phase is 276 km.

Phase III: Remaining roads with at least 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.

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

1. Physically segregated bicycle tracks on routes which have >30m ROW.
2. Recommended lane width for MVs 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:
 - No free left turns for MVs
 - Modification of traffic signal cycles
 - Roadside furniture to ensure safe bicycle movement and minimise interference from motorised two wheelers.

Capacity estimates of the new cross-sections shows three to four fold increase in number of passengers travelling through the same corridor. The new cross sections also result in enhanced efficiency of the public transport buses that can be given the curbside lane or central two lanes for buses as per the site demand. Physically segregated lanes also improve safety of the vulnerable road users by reducing the conflicts between motorised and non-motorised modes.

PLANNING FOR HEALTHIER TRANSPORT

Buses and non-motorised modes of transport will remain the backbone of mobility in LIC mega-cities. Bus use has to be increased without increasing pollution or the rate of road accidents. This would be possible only if the following conditions are met:

Public transport:

1. The cost effectiveness of metro rail systems be evaluated very carefully. Current evidence suggests that metro rail systems, especially the construction of two or three lines at great cost, do not help in reduction of private vehicle use, congestion or pollution.
2. Design and development of modern and sophisticated high capacity bus systems be given priority in megacities of Asia.
3. Introduction of bus engine and transmission technologies that ensure clean burning and efficient combustion at the passenger loads and driving cycles experienced in Asian megacities.
4. Safe entry and exit procedures for bus passengers. This would include all buses to be equipped with closing doors, low floors, and appropriately designed bus stands.
5. Operation of buses at safe speeds. This will require setting of realistic trip times and installation of speed limiting devices in buses.

6. Bus stop locations that ensure route changes are convenient and safe for commuters.
7. Development of safer bus front designs and standards. Since a significant proportion of road user fatalities involve buses in low income countries, it would be very important to develop such designs. Particularly in view of the fact that increases in bus numbers can mean an increase in conflict between them and other road users. Recent studies suggest that such designs are technically feasible.

Segregated lanes for non-motorised transport and safer pedestrian facilities:

1. Urban and road design characteristics that ensure the safety of pedestrians and bicyclists.
2. Provision of segregated bicycle lanes on all arterial roads.
3. Wider use of traffic calming techniques, keeping peak vehicle speeds below 50 km/h on arterial roads and 30 km/h on residential streets and shopping areas.
4. Convenient street crossing facilities for pedestrians.

The above recommendations have to be considered in an overall context where safety and environmental research efforts are not conducted in complete isolation. We have to move toward adoption and implementation of schemes that remain at a human scale and improve all aspects of human health. The authors of a report on integration of strategies for safety and environment published by the OECD suggest the following guidelines for policy makers:²⁷

- Ask leading questions about safety and environmental goals at the conceptual stage of the project and look beyond the immediate boundaries of the scheme.
- The safety and environmental consequences of changes in transport and land use should be made more explicit in technical and public assessments.
- There should be simultaneous consideration of safety and environmental issues by involving all concerned agencies.

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