

## **Public Transport Research Challenges in India**

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### Biographical Sketch

**Geetam Tiwari** obtained her B. Arch from the University of Roorkee and Master of Urban Planning and Policy, and Ph.D. in Transport Planning and Policy, with specialisation in travel demand models and traffic flow studies from the University of Illinois, Chicago. Currently she is TRIPP Chair Associate Professor for Transport Planning at the Indian Institute of Technology Delhi and Alderbrastka Guest Professor for sustainable urban transport at the Chalmers University of Technology, Sweden 2007-2009. She has extensive research experience in dealing with transportation issues of special relevance to low income countries. These include development of systems and designs that would make transportation efficient and safer with a special focus on vulnerable road users and commuters. She has published over 60 research papers on transportation planning and safety in national and international journals and peer reviewed seminar proceedings. Edited four books on transportation planning and road safety. Received International Velocity Falco Lecture Prize, Barcelona, Spain, the Stockholm Partnerships award for local impact, innovative thinking and a potential for replication or transferability. And Centre for excellence grant from Volvo Research and educational foundations(VREF).

### Abstract

Urban transport and urbanization are closely interlinked. Therefore planning for urban transport starts at understanding the urbanization process. India is only 30% urbanized at present, however, is expected to double its urban population in next twenty years. An important characteristic of Indian urbanization has been growth of informal sector as an integral part of urban system. If public transport has to become competitive as a choice mode, it must be designed as a system not merely introducing bigger vehicles(buses) or rail technology. The system components include infrastructure design, traffic operational strategies, vehicle design, institutional structure and financial model designed to meet the specific requirement of public transport uses and operators. Our TRIPPP colleagues have been working on various aspects of public transport systems. In this paper a summary of research work in the area of planning and policy for public transport system is presented.

## Public Transport Research Challenges in India

Urban transport and urbanization are closely interlinked. Therefore planning for urban transport starts at understanding the urbanization process. India is only 30% urbanized at present, however, is expected to double its urban population in next twenty years. An important characteristic of Indian urbanization has been growth of informal sector as an integral part of urban system. Urban transport in Indian cities is heterogeneous, reflecting the heterogeneity in the socio-economic and land use patterns. It is dominated by walking trips, non-motorized modes such as bicycles and rickshaws, and depending on the size of the city, motorized para-transit and public transport. Amongst personal motorized vehicles, two wheelers dominate the urban mobility sector. Given the present concerns of global (CO<sub>2</sub>) and local pollution, fuel security and urban land as a scarce resource, there is a consensus at policy level that public transport has to be promoted to ensure sustainable mobility to all. Public transport systems in Indian cities have to compete with the mobility offered by a motorized two wheeler and economics of running a para transit system by the informal sector. Two wheelers provide convenient and economical mobility, however also have the highest safety risk for the user. Motorized para transit systems (four-ten seater three wheeled vehicles) move like fixed route taxi systems. Operators in the informal sector compromise on environmental and safety regulations to compete in the free market. The result is large social cost in terms of increased safety risks and polluted environment. If public transport has to become competitive as a choice mode, it must be designed as a system not merely introducing bigger vehicles (buses) or rail technology. The system components include infrastructure design, traffic operational strategies, vehicle design, institutional structure and financial model designed to meet the specific requirement of public transport uses and operators. Our TRIPPP colleagues have been working on various aspects of public transport systems. In this paper a summary of research work in the area of planning and policy for public transport system is presented.

Our research has focused on exploring the following questions regarding public transport in Indian cities:

1. Public transport benefits people who do not have personal motorized vehicles.
2. How can we improve estimates of public transport demand?
3. Transport pricing can result in optimal road usage.
4. Does safety risk reduce with increase in public transport vehicles?

1. Public transport benefits people who do not have personal motorized vehicles:

Metro rail projects have been promoted as a sustainable mode of transport in all cities. It is a capital intensive project and requires at least 20 times more investments than a road based public transport project. The justification for these projects is often based on the social benefits including improved access to users of the system, environment and safety benefits. At the same time, the “users” of the transport system are a heterogeneous mix of people of different socio-economic classes, with different needs and desires and differing needs of movement. These differential concerns make the task of assessing the feasibility of a project more complex – some users may benefit, some may not, and some may not be affected at all. Also, there may be a category of non-users of the project – people who are not the target group or the stakeholders – who may experience an indirect impact of the project.

Anvita Arora (2007) studied the impact of Delhi metro on poor households residing in the proximity of the project. The Delhi Metro is one of the largest urban transport projects implemented by the government in any Indian city in the recent past. It is a representative case study of a capital-intensive urban transport project promising to accrue high benefits of accessibility and decongestion. DMRC (2005) lists out the benefits of Metro as “Time saving for commuters, reliable and safe journey, reduction in atmospheric pollution, reduction in accidents, reduced fuel consumption, reduced vehicle operating costs, increase in the average speed of road vehicles, etc.” The people living along the metro line, however, belong to differential socio-economic groups hence the expected improvement in accessibility provided by the metro needs to be understood differentially – especially, what would be the impact on the accessibility of the urban poor. The Delhi Metro rail has acquired large tracts of land along its lines. This land acquisition has led to demolition of existing structures and large scale evictions. Apart from other commercial and residential evictions it has also caused eviction of low-income settlements for its construction and is a good example of how large infrastructure projects cause eviction and resettlement of the urban poor.

The methodology used for the study is based on assessing the impact of the Delhi metro rail on the urban poor living in the vicinity of the metro line and those relocated due to the metro construction by collecting household survey based primary data. This data is used to derive indicators of accessibility, mobility and SEWB. The indicators are then aggregated into indices of accessibility, mobility and SEWB by using the Principal Component Analysis technique. The change in indicators and indices in the before and after metro scenarios is used to assess the significance of the impact of the metro project on the urban poor. The correlation between accessibility, mobility and SEWB is modeled using linear regression to illustrate that the change in accessibility and mobility due to a transport project changes the SEWB of the community. Accessibility, mobility and Socio economic well being can be defined as:

**Accessibility** :Accessibility is a description of the proximity of destinations of choice and the facilitation offered by the public transport systems to reach them.

1. **Landuse accessibility**: geographical allocation of opportunities, dependent on urban planning and land use distribution and is represented by the distance to opportunities.
2. **Transport accessibility**: how the transport system facilitates access to opportunities and is dependent on the quality of the transport system (civil infrastructure and transport modes available).

**Mobility** Mobility is both the ability to travel to destinations of choice and the amount of movement necessary to do so.

1. **Increase in the amount of movement** – negative
  - social, economic and environmental costs.
  - “Forced mobility” due to suburbanization, relocation
2. **Ability to move** – positive
  - Difference between plants and animals, Expression of freedom
  - “Forced immobility” of poor, women, elderly, disabled is negative

**Socio-economic well being (SEWB)** Socio-economic well-being is defined as the status of a household where the basic social and economic needs for survival are fulfilled and the household has the capacity to improve its quality of life.

SEWB can be measured with the parameters of literacy and education, employment, income and consumption, shelter and urban services, health and nutrition, environmental concerns, safety and security, time use and availability.

The impact of the metro project on the poor households has been analyzed by this study in two phases. The first phase studied the change in the identified indicators of accessibility, mobility and socio-economic well being (SEWB) to illustrate the impact. The results of the study show that for the poor households in the vicinity of the metro line there is no significant impact on the indicators of SEWB and mobility. With regard to the accessibility of the households, while the landuse accessibility remains unchanged, the transport accessibility has changed as distance to the bus stops has increased for 19% of the households and bus services have become non-existent for 33% of the households.

On the other hand, for poor households relocated due to the Metro there has been a significant impact on the indicators of accessibility, mobility and SEWB. The land-use accessibility has deteriorated as distance to education, health services and other urban services have increased for 52%, 63% and 52% of the households respectively. The transport accessibility has deteriorated even more as distance to bus stop has increased for 72% of the households and the bus frequency has decreased, on an average, from 5 min to 63 min (almost 13 times). The mobility of the households has increased significantly. The PCTR for work has increased for 49% of the households and decreased for 30%, implying change in the number of trips made for work in the households. The share of NMVs amongst the mode used has decreased for 59% of the households. The mobility indicators for travel to work – distance, time and cost – have increased for 83%, 82% and 61% of the households respectively. Due to the relocation the SEWB indicators most adversely affected are female literacy (21% decrease), residency (100% decrease), Household income per person (66% decrease), Infrastructure rank score (33% decrease and 61% increase), and employment (8% decrease and 14% increase). The indicators of adult literacy and vehicle ownership show least change with 82% and 94% respectively in the no change category.

The correlation of SEWB to accessibility and mobility was studied to study the impact of change in accessibility and mobility. The results indicate that SEWB is affected by indicators of both accessibility and mobility. SEWB is negatively correlated to the spatial distance to education health and other urban services. The model indicates that SEWB is positively correlated to PCTR for work, education and other purposes and it is negatively correlated to travel distance, time and cost. The significance of indicators changes with change in situation like introduction of the new metro line and relocation due to it. The study shows that the PCTR for work is positively correlated with SEWB and has the highest coefficient in all datasets, indicating the mobility for work is important in ensuring their SEWB, whatever is their situation. Also, the cost of travel has no significance in explaining SEWB of the urban poor but it becomes significant when they are relocated and now have to pay heavily for the travel.

The profile of the metro users (as compared to bus users) shows that they travel longer distances – 33% bus users and 19% of metro users travel upto 20 km a day and they have more travel expenditure – 42% of bus users spend upto Rs. 15 a day as travel expenditure while only 2% metro users belong to this category. The metro users make more access trips – 48% of the metro users have to make more than 2 access trips (one at each end of the journey) for every main line haul (MLH) trip while only 4% bus users belong to this category. The travel characteristics of the access trips shows that, compared to bus users, 27% of the metro users travel longer distances, 67% of metro users spend more time, and

19% pay more to access the metro, than they spend on the metro itself. The modes used for access trips shows that the metro users walk less for access – 19% of metro users and 77% of bus users do not use vehicles for access. The monthly travel expenditure made by the metro and bus users, when seen as a fraction of the average monthly income of the poor households shows that a low-income-resident cannot use the metro unless s/he is willing to spend at least 30% of monthly income on travel.

The study concludes that relocation due to the metro has had a significant negative impact on the SEWB of the poor households. It illustrates that though the urban poor are not expected users of the metro, their accessibility and mobility and hence their socio-economic well-being is affected by its introduction in the urban transport system. While they may not be expected beneficiaries of the project, the dis-benefits accrued to them due to the project need to be assessed, and hence mitigation measures should be planned when proposing the project. Hence, it is important to conduct Socio Economic Impact Assessment (SEIA) studies for a new project over disaggregated groups, specifically including impacts on the most vulnerable group – the urban poor.

### 3. How can we improve estimates of public transport demand?

Since large sums of money and other scarce resources are invested in creating transport infrastructure, it is important to avoid projects which fail to provide expected benefits. Demand forecasts for metro projects in different Indian cities show gap between estimation and actual riderships. Mukti Advani(2007) studied the impact of access and egress trips in public transport demand models.

Advani's study(2007) develops a demand estimation model including details of distance, time and cost of access and egress trips. Model is run using conventional traffic zone system where 90% of zone's size is in the range of 2-5 sq km. Since this size hides the details of access and egress trips which tend to be much smaller, new zoning system based on creating zones around public transport stops/stations has been used to capture the details of access and egress trips. i.e. 95% zone's are of area less than 1 sq.km. First database set (database set-1) is created for zoning based on conventional traffic zones with artificial collectors and second database set (database set-2) is based on creating zones around the service area of public transport service stops/stations. Mode choice model has been run on both zoning systems to estimate the ridership.

The demand estimation model includes ratio of access and egress trip and main haul line trip and/or total trip characteristics. The first phase of the metro is complete and remaining phases are at various stages of implementation. Since there is a significant gap between the estimated and the actual ridership of phase I, the proposed demand model has been calibrated for phase I. This has been used to estimate the ridership on the other corridors of metro.

Commuter travel characteristics collected in the primary surveys have been used for developing the demand estimation model. Nested logit models for modeling mode choice behavior of different commuters have been developed. Statistical test of significance of different parameters shows that not only the absolute value of access and egress trips but the ratio with main haul line trip is also significant. The multinomial logit model implies equal competition between all pairs of alternatives. Though in both the database sets, this is not the

case when we consider choice between car, two-wheeler, bus and metro. Therefore nested logit models have been developed for both the database sets. A comparison of the sensitivity between different modes leads to a final nest for further analysis. The final nested model of database set-1 includes access and egress time, access and egress cost, main haul line time, ratio of access-egress distance with the main haul line distance, ratio of access-egress time with total time and the vehicle ownership. While developing model for database set-2, it shows different estimation parameters i.e. access and egress time, total time, ratio of access plus egress time to main haul line time and ratio of access plus egress distance to total distance. Both the database sets have different results for nested logit model i.e. after full metro network construction in year 2021, 7 to 16% trips according to database set-1 and 15 to 22% according to database set-2 of the total motorized vehicular trips would be made by metro. Approximately 15 to 30% trips of public transport would be made by the metro as per database set-1 and 27 to 36% according to database set-2. All parameters have been tested and significant parameters have been used to prepare the final logit model. Interestingly both the types accept the same nesting of modes and both the nested logit models show the significant sensitivity between bus and two-wheeler choice.

The mode choice model developed in this study predicts that after the construction of the full network of Delhi metro (256 km) in year 2021, number of trips made by metro will be between 1.38 to 3.17 million (7 to 16 percent of the total estimated trips in Delhi in year 2021) as per database set-1 and 3.0 to 4.3 million (15 to 22 percent of the total estimated trips in Delhi in year 2021) as per database set-2. Database set-1 based on conventional zoning and artificial collectors does not capture the details of access and egress trips. Therefore zoning based on smaller zones around public transport stops is recommended for better estimation of trips especially of public transport demand. Even after the construction of full network of 256 km, Delhi metro would be able to carry 15 to 31% trips of the total trips made by public transport and 85% or 69% of public transport trips will be on bus according to database set-1 results while as per database set-2, metro trips ranges between 27 to 36% of public transport trips. Since the majority of the city trips are short trips (less than 10 km), a road based system provides better accessibility as compared to the metro system. While planning new metro systems the demand estimation must be reviewed in this context. Road based systems which provide better network connectivity and shorter access distance can offer a viable alternative to private vehicles.

#### 4. Transport pricing can result in optimal road usage

The rapid pace of urbanization and emergence of mega-cities have resulted in the problems of environmental pollution, traffic congestion, accidents, noise, health hazards and overall environmental degradation resulting from the use of urban transport. Road users either completely ignore or insufficiently take into account these negative externalities while making their travel decisions. Clearly, when road capacity is relatively fixed, the economic efficient solution is to price the use of roads differentially by setting road tolls/congestion tolls, which reflect the scarcity value of road services.

Akshay Sen(2006) explored the optimal road pricing mechanism for achieving efficient use of road by public and private vehicle users.

The current study has attempted to address the issues and questions related to the phased approach to introduction of road pricing based on the principle of marginal social cost pricing. The problems considered in this study were the following:

- How the negative externalities (congestion, pollution, accidents, noise, etc.) generated by the excessive use of urban road transport can be tackled effectively?

- How to quantify these negative externalities into total external costs generated by the use of road transport?
- What is the appropriate price level and price structure for urban transport, under the prevailing constraints (political feasibility, pre-existing taxes, distribution of competencies over govt. levels, limited differentiation of congestion taxes)?

This study has estimated the marginal external costs of congestion, air pollution, accidents and noise in Delhi. There is enough knowledge on the monetary values of external costs to start with a pricing reform in the transport sector. In urban areas congestion is becoming the main transport problem and it represents over 90% of all marginal external costs. From the research this study finds that depending on the existing pricing and regulatory mechanism and on the package of policy instruments used, welfare gains from marginal cost pricing varied between Rs.7.27 million/day and Rs.36.30million/day for Delhi or Rs. 0.56 and Rs. 2.81 per capita per day, when parking pricing policy is ignored. When improved parking pricing along with optimal public and private pricing are combined, then the welfare gain from marginal social cost pricing is found to be Rs. 99.43 million per day for Delhi or Rs. 6.30 per capita per day.

Optimal urban road pricing schemes have two effects: (i) of discouraging road use at least at certain times and certain parts of the road network; and (ii) of transferring cash from private persons to public funds. In qualitative terms, urban transport pricing trials or/and simulations have confirmed that urban road pricing does have a meaningful potential in reducing traffic (and therefore congestion and the environmental nuisances associated with urban mobility), and, possibly, in modifying the users pattern of behaviour (trip choice, modal choice, etc.). Pricing measures are effective in changing people's behaviour and travel patterns. The changes need not be dramatic to have a noticeable effect on the traffic conditions. Car users change timing, route or destination of their trip more readily than mode. The analyses carried out in this study show that implementation of full optimum pricing will result in reduction of traffic by 32% and increase in the government revenue from urban transport by 156%.

Optimal urban road pricing is likely to increase prices for car use in congested urban conditions. Public transport will become more competitive. Constructing a package of pricing instruments is an important component of the selection of a successful implementation plan for marginal social cost pricing. The analysis of this study showed that successive combination of pricing instruments yield more welfare gains than introducing them in isolation. For example, when improved parking is introduced as the single pricing instrument, the welfare gain is only 0.03% over the reference situation. But when it is combined with optimal private and public transport pricing, the welfare gain increases to 4.69% over the reference period.

A property of a successful implementation path is that it transmits correct and plausible pricing signals to the public. Analysis carried out in this study shows that optimal public transport pricing, as long as peak car use is not priced correctly, requires to be increased in both the peak and off-peak period though the increase in peak period is longer. Once optimal road pricing is introduced, peak public transport prices require to be increased strongly again. This conflict between short and long-term signals has to be traded off with the welfare gain that can be achieved by using very low public transport prices in the peak.

The issue of division of various policy instruments between different levels of government creates co-ordination problem between them regarding the control of these instruments. In

India, for example, tax on fuel such as petrol and diesel taxes are usually determined at the central government level while fixation of tolls is a state subject. Similarly, parking fees are typically fixed at the city government level. The study found that as there are many interactions and many externalities between the two levels of government, a division of roles between the two government levels does not guarantee an efficient pricing outcome. The precise result will depend on the institutional set-up and on the correspondence between the objective functions of the two government levels.

On the issue of role of labour supply in determining optimal transport pricing in the case of multiple trip purposes, the study finds that relaxing strict complementarity assumption between commuting transport and labour supply can enable one to determine unique optimal tax rates for commuting transport, non-commuting transport and labour supply. For a given labour tax rate, the study finds that, commuting trips should be taxed less than non-commuting trips, the more complementary commuting is with labour. Introduction of differentiated transport tax system in Delhi for a given level of labour tax leads to a welfare gain of 9.42 percent of generalised income, an increase in labour supply by 47%, a traffic volume reduction of 22% and increased peak period speed of over 22% thereby reducing congestion conditions considerably in Delhi.

Despite the growing awareness of efficiency and welfare gain achieved from marginal social cost pricing in urban transport, acceptability, both public and political, has been identified as the main obstacle for implementing marginal cost pricing in practice. Reasons behind opposition to efficient pricing are manifold: the distributional impacts are considerable, the benefits are not obvious to transport users, important behavioural changes might be induced affecting people's daily habits and even location choices. The fact that road pricing – at least in the first place – involves a transfer of cash from private travellers to public institutions, is likely to be a major impediment to its public acceptability. Therefore, to render marginal cost pricing schemes politically and publicly acceptable, it is probably necessary to recycle the revenue generated in such a way as to keep most population subgroups at least equally well off. Such redistribution schemes appear by no means infeasible, but in the process of redistribution large parts of the initial efficiency gain may, in important cases (i.e., if there is a non-zero shadow price of public funds), be lost. Thus, marginal cost pricing accentuates the traditional conflict between the goals of economic efficiency and equity.

Optimal Pricing can be made acceptable to all stakeholders. People need to be convinced about the effectiveness of the measures, use of revenues and anonymity of the system. By making pricing part of a package of policy measures, by offering alternatives to car use and by using the revenues in the most profitable way for the local context, be it in transport or in other sectors, efficient pricing can be acceptable to policy makers and citizens and other stakeholders. A “clever and intelligent” marketing strategy and sound consultation process are crucial for the success of the package.

There is considerable debate in the literature on the issue of implementability of optimal road pricing. This study finds that optimal transport pricing can be implemented. The concept of marginal cost pricing can be translated into concrete pricing or taxation measure using existing technology. Simple “second best” approaches, such as cordon tolls and peak/off-peak price differentiation, can often achieve almost as much as the theoretically optimal solutions. Optimal pricing will change the structure of taxes and charges from fixed and blunt measures to more variable ones levied at the point of use.

#### 4. Does safety risk reduce with increase in public transport vehicles?

In most transportation scenarios, reliance on buses has a positive impact on air quality because they pollute less per person kilometer and congestion because of their smaller road-use footprint. In addition to these benefits, it is usually assumed that buses are among the safest modes of transport available because they are much larger in size and mass than most other road vehicles. It is no doubt true that a large number of biomechanics and crash investigation studies have confirmed that occupants of buses are at much lower risk of dying in the event of a crash (see Bhalla et al. 2006 for a comparison of case fatality rates for different vehicles).

However, bus trip or any public transport trip begins and ends as a pedestrian trip as access and egress trip. Therefore risk in a public transport trip includes risk faced in access trip, often as pedestrians, risk to the bus occupants inside the vehicle and risk that vehicle poses to the other road users. In an ongoing study (Bhalla et al) we investigate how a shift in travel patterns that result in increased reliance on buses will affect total road traffic fatalities and the distribution of victim-types. We do this by adapting a generalized exposure-outcome methodology developed by us in a previous study (Bhalla et al. 2006) to the local travel and injury patterns in New Delhi. The model relies on computing an exposure-outcome response function from existing road use modal shares and the resulting traffic fatalities. We compute the fatality outcome that will result from increasing bus use (mode shift from car to bus and from scooter to bus) from the change in exposure by assuming that the fatality response per unit exposure remains constant.

We estimated current levels of exposure (Table 1) of road users to threats from different vehicles as proportional to their roadway use based on 42 mid-block traffic volume counts (CRRI, 2002). Since pedestrians were not counted, we adjusted the weighted mean of the observed vehicle-mix based on a 2004 travel survey (Tiwari, 2004). We combine this with vehicle occupancy data (Mohan et al., 1997), to estimate the people-mix (i.e. or road user mix). Based on Bhalla et al. 2006, the exposure of different road users to this vehicle mix can be estimated as the product of vehicle-mix and people-mix. Thus, for instance, in the existing travel scenario described by Table 1, the exposure of scooter riders to cars is proportional to 0.25 (fraction of scooters in the people-mix) times 0.23 (fraction of cars in the vehicle-mix).

Table 1: Exposure: Existing vehicle-mix and people mix on the roads of New Delhi.

	Vehicle-Mix	Vehicle-Mix (incl ped)	Occupancy	People-Mix
<b>Pedestrian</b>	-	0.32	1	0.32
<b>Bicycle</b>	0.12	0.08	1.05	0.08
<b>Bus &amp; Truck</b>	0.09	0.06	40	2.55
<b>Car</b>	0.34	0.23	2.2	0.51
<b>Scooter</b>	0.32	0.22	1.15	0.25
<b>Auto Rickshaw</b>	0.13	0.09	1.76	0.15
<b>Total</b>	1.0	1.0		3.9

#### Notes

1. Vehicle-mix is the distribution of vehicles on the street. People-mix is the mix of road users after accounting for vehicle occupancy. Note that while the vehicle mix is listed in fractions (i.e. sum to 1), people mix does not. Vehicle occupancy is based on Mohan et al. 1997. Since they did not measure bus occupancy, we have assumed 40 occupants per bus.
2. Bicycle includes all non-motorized vehicles (such as cycle rickshaws); Bus and truck include all vehicles larger than passenger min-vans; Car includes cars, mini-vans, Sports Utility Vehicles and taxis; Scooter includes all motorized two wheelers (such as mopeds and motorcycles)
3. Vehicle-Mix is a weighted mean of 42 mid-block location traffic volume counts performed in February 2002 in New Delhi. (CRRI 2002). A total of 3.1 million vehicles were counted during these surveys and the roadway use fractions shown were

computed by weighting the distribution at each site by the total vehicle count at the site. The counts were conducted during the day (6am – 9pm). Trucks, which are present in much higher volumes in the night, are likely to be underrepresented. Pedestrians were not included in these traffic counts. Vehicle-Mix is adjusted to include pedestrians based on trip lengths and trip modal shares reported in a 2004 travel survey (Ref:Tiwari, 2004).

4. Vehicle occupancy is based on Mohan et al., 1997.

In order to estimate the fatality outcome because of this exposure, we analyzed police reported road traffic fatalities and developed a who-killed-whom matrix,  $fatal_{threat-victim}^{existing}$ , shown in table 2. The response to small changes in exposure due to shifts in travel mode can be estimated by

$$fatal_{threat-victim}^{new} = \exp_{threat}^{new} \exp_{victim}^{new} \frac{fatal_{threat-victim}^{existing}}{\exp_{threat}^{existing} \exp_{victim}^{existing}}, \quad \text{--- [1]}$$

where the superscript *new* is used to indicate the new distribution of people and vehicles on the road because of the mode shift,  $\exp_{threat}$  is the vehicle-mix, and  $\exp_{victim}$  is the people-mix.

Table 2: Fatality outcome due to existing exposure: Who-killed-whom matrix

▼Victim▼	Threat (Impacting Vehicle)							
	Pedestrian	Bicycle	Bus & Truck	Car	Scooter	AutoRickshaw	Single Veh	Total
Pedestrian	0	0	574	238	65	13	0	890
Bicycle	0	0	148	42	12	3	0	205
Bus & Truck	0	0	30	0	0	0	54	84
Car	0	0	29	9	0	1	12	51
Scooter	0	0	328	95	15	4	30	472
Auto Rickshaw	0	0	16	15	0	0	8	39
Total	0	0	1124	400	92	21	104	1741

Source: Delhi traffic police in 2004 (Ref)

1. Each entry in the matrix lists the number of fatalities caused among a particular victim type by a particular impacting vehicle. For example; 95 scooter riders were killed in scooter-car crashes.
2. 41 fatalities reported by the police were excluded: In 11 cases the impacting vehicle did not belong to the vehicle types chosen; and in 31 cases the victim could not be classified among the victim types chose (1 case involved both other vehicles and other victims).
3. In 625 cases the impacting vehicle was not known. Over 95% of these cases were either pedestrians, bicyclists or scooter riders. These are predominantly hit-and-run cases without witness. These cases were distributed among cars and trucks in proportion to the known cases. Bus crashes usually have witnesses; and scooters and Auto Rickshaws are unlikely to hit-and-run because of extensive damage they suffer in a fatal crash. Single vehicle crashes are those that involve overturning and impact with a fixed-object.

We apply this methodology to estimate the fatality outcome of travel mode-shifts that result in increased bus-use: shift from car-use to bus-use, and shift from scooter-use to bus-use. In the first case, we assume that 5% of the existing population of car-users is shifted into buses. In the second, we consider the outcome of moving 5% of scooter-users into buses. These mode shifts result in changes to both the vehicle-mix as well as the people-mix. We assume that vehicle occupancy does not change and the additional demand for buses is filled by additional buses. Similarly, reduced demand for cars leads to a reduction in the number of cars. Furthermore, since bus-use requires pedestrian access trips (i.e. between the bus stop and origin/destination), the number of pedestrians should increase with increasing bus-use. Thus, we assume that each unit of new exposure as a bus-user results in an additional half unit of exposure as a pedestrian.

## Results

In order to understand the fatality outcome of the increased bus-use scenarios, we need to examine the existing exposure (Table 1) and the resulting fatality outcomes. Pedestrians dominate the vehicle-mix (32%) followed by cars and scooters (23% and 22%, respectively). While buses represent the smallest fraction (6%) in the vehicle-mix, their high occupancy (40 people) implies that the people-mix on the roadway is dominated by bus users. In fact, there are 8 times more bus-users than there are pedestrians, who rank second in people-mix.

Despite the small proportion of vehicles that are buses, Table 2 shows that buses are the impacting vehicle in most road deaths (65%), followed by cars (23%). Pedestrians are the most common victims (51%), followed by scooter riders (27%). For both, pedestrians and scooter riders, however, buses represent the primary threat.

These exposure and fatality patterns suggest that buses pose a much higher fatality risk per unit exposure, as confirmed by Figure 1, which shows the risk for different victim-threat combinations. In fact, buses pose risks to pedestrians, bicyclists and scooter riders that are an order of magnitude higher than that posed by cars.

Thus, the increased bus use in both two mode-shift scenarios considered leads to higher traffic fatalities (Tables 3 and 4) because it involves substituting low risk travel patterns with ones that have higher risks. In each scenario, the increased bus-use result in a larger number of pedestrians (due to bus-stop access trips) and buses (to cater to the higher bus-use demand), the threat-victim pair that has one of the highest fatality risk per unit exposure in Figure 1.

In the first case, shifting car occupants to buses causes an additional 65 pedestrian deaths (Table 3) almost primarily due to an increase in the number of deaths due to crashes with buses. Because there are fewer cars, there are two fewer car related deaths. However this is outweighed by 57 additional deaths due to crashes with buses. The net result is an additional 60 deaths amongst all road users.

Since scooter-use is a high risk travel mode, in the second scenario, the shift from scooter-use to bus-use, results in a smaller increase in deaths than the shift from car-use to bus-use (first scenario). Nevertheless, the gains from reducing scooter deaths (23 fewer) are more than outweighed by the large increase in bus related deaths (71 additional), primarily due to impacts with buses. The net impact of the mode-shift is 49 additional deaths amongst all road-users

Table 3: Change in traffic fatalities resulting from shifting car occupants to buses

		Threat (Impacting Vehicle)							
▼Victim▼	Pedestrian	Bicycle	Bus & Truck	Car	Scooter	AutoRickshaw	Single Veh	Total	
Pedestrian	0	0	52	6	5	1	0	65	
Bicycle	0	0	1	-2	0	0	0	-1	
Bus & Truck	0	0	1	0	0	0	1	1	
Car	0	0	-1	-1	0	0	-1	-3	
Scooter	0	0	3	-5	0	0	0	-1	
Auto Rickshaw	0	0	0	-1	0	0	0	-1	
<b>Total</b>	0	0	57	-2	5	1	0	60	

Table 4: Change in traffic fatalities resulting from shifting scooter occupants to buses

		Threat (Impacting Vehicle)							
▼Victim▼	Pedestrian	Bicycle	Bus & Truck	Car	Scooter	AutoRickshaw	Single Veh	Total	
Pedestrian	0	0	49	19	2	1	0	71	
Bicycle	0	0	1	0	-1	0	0	0	
Bus & Truck	0	0	0	0	0	0	0	1	
Car	0	0	0	0	0	0	0	0	
Scooter	0	0	-15	-5	-1	0	-2	-23	
Auto Rickshaw	0	0	0	0	0	0	0	0	
<b>Total</b>	0	0	35	14	0	1	-1	49	

## Discussion and Interpretation

Public transit systems pose a strong appeal to transportation engineers because they contribute less pollution and congestion, and provide an egalitarian solution to the mobility needs of a city. However, the perception that they result in increased safety may not always

be correct. Our analysis of current road traffic injury statistics in New Delhi found that buses were involved in fatal crashes in a disproportionate to their use. As a result, increasing bus use would result in increasing traffic fatalities, primarily among pedestrians, the most vulnerable road users. Of course, New Delhi is not a typical city, even amongst cities in developing countries. However, it is likely that our key result that increased reliance on bus use will result in a higher injury death toll can be generalized to any urban region where buses are currently involved in a large number of fatal accidents. Buses are widely reported to be over represented in traffic crashes in cities in developing countries. See, for instance, Maunder and Pearce, 2000 (Nepal, India, Thailand, Tanzania, and Zimbabwe), Mirza et al., 1999, (Karachi, Pakistan), Jacobs and Aeron-Thomas, 2000, (Kenya, Botswana and South Africa), and Mohan and Tiwari (Mumbai, India). On the other hand, a similar analysis in cities where bus travel is currently safe will likely show increased safety from increased bus-use. This is likely true of many cities in high income countries where the net risk posed by buses to both occupants and non-occupants is lower than that from other road vehicles. See, for instance, Litman and Fitzroy 2005, Koornstra et al. 2002,). Since these studies demonstrate that buses have a potential to be safe, it is important to understand why the experience of low income countries has been different.

For the particular case of New Delhi, we have examined police and media reports and have found the following common pattern in fatal crashes involving buses. Passengers waiting at bus stops are often struck by buses as they arrive. New Delhi has a large fleet of private buses that compete for passengers at bus stops. This results in dangerous maneuvers especially near bus stops, where passengers are often waiting on the street due to missing or poor quality bus shelters. Another common crash scenario identified involved passengers that fell off buses and were crushed under the vehicle while boarding or alighting. This is a common occurrence because of overloaded buses that fail to come to a full halt at bus stops. It should be noted that both of these categories were often classified as pedestrians in police fatality tabulations. In addition to pedestrian deaths, buses are also responsible for a disproportionately large number of deaths amongst bicyclists, cycle rickshaws, and scooter riders. We suspect that one of the primary factor that contributes to these crashes is that buses in New Delhi are required to travel in the left most (slowest) lane where they share the same road space used by various slow moving vehicles and other vulnerable road users.

The initial results of this study show that unless suitable infrastructure changes are accompanied with the introduction of public buses, risks imposed by buses outweigh the benefits.

### Concluding Remarks

Promoting public transport as a choice mode is a requirement to meet the future mobility demand. This has to be achieved in the context of high ownership of motorized two wheeler, presence of informal sector in urban areas and high residential density of slum population in Indian cities.

Our research has highlighted the need for creating an equitable public transport systems. Rail systems alone do not meet this criteria as shown by Arora(2007). It illustrates that though the urban poor are not expected users of the metro, their accessibility and mobility and hence their socio-economic well-being is affected by its introduction in the urban transport system. The monthly travel expenditure made by the metro and bus users, when seen as a fraction of the average monthly income of the poor households shows that a low-income-resident cannot use the metro unless s/he is willing to spend at least 30% of

monthly income on travel. While they may not be expected beneficiaries of the project, the dis-benefits accrued to them due to the project need to be assessed, and hence mitigation measures should be planned when proposing the project. Hence, it is important to conduct Socio Economic Impact Assessment (SEIA) studies for a new project over disaggregated groups, specifically including impacts on the most vulnerable group – the urban poor.

Sen(2007) makes a case for marginal social cost pricing for urban areas. Constructing a package of pricing instruments is an important component of the selection of a successful implementation plan for marginal social cost pricing. The analysis of this study showed that successive combination of pricing instruments yield more welfare gains than introducing them in isolation. For example, when improved parking is introduced as the single pricing instrument, the welfare gain is only 0.03% over the reference situation. But when it is combined with optimal private and public transport pricing, the welfare gain increases to 4.69% over the reference period.

Advani(2007) is working on improving the demand forecasts for public transport trips and shows the importance of including the details of access and egress trips in the demand model. Zoning methodology also requires a different strategy to capture the details of access and egress trips. Delhi metro would be able to carry between 27 to 36% of public transport trips. Nearly 40% metro trips will be dependent on rickshaws. Since the majority of the city trips are short trips (less than 10 km), a road based system provides better accessibility as compared to the metro system. While planning new metro systems the demand estimation must be reviewed in this context. Road based systems which provide better network connectivity and shorter access distance can offer a viable alternative to private vehicles.

Bhalla et al(2006) high light the importance of infrastructure changes to ensure safety benefits of public buses. Increasing bus use in the mixed traffic conditions would result in increasing traffic fatalities, primarily among pedestrians, the most vulnerable road users.

The above discussions include some attempts to understand the complexity of public transport systems. However, future research must include understanding the interrelationships amongst these and details of geometric standards, traffic flow and traffic operational standards to meet the special need of public transport systems.

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