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Traffic Flow and Safety: Need for New Models for Heterogeneous Traffic

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INTRODUCTION

Knowledge of fundamental traffic flow characteristics–speed, volume and density–and associated analytical techniques are essential requirements in planning, design, and operation of transportation systems. The fundamental characteristics have been studied at microscopic and macroscopic levels. Existing traffic flow models are based on time headway, flow, time–space projectory, speed, distance headway and density. These have lead to the development of a range of analytical techniques: demand–supply analysis,capacity and level of service analysis, traffic stream modelling, shock wave analysis, queuing analysis and simulation modelling. The focus of this research has been homogenous traffic conditions–traffic which consists primarily of cars or motorized vehicles of similar characteristics. We are now faced with a situation where more than half of the world's population is living in megacities in the developing region. Large differences in income levels and social disparities have lead to the development of 'cities within cities'. Each level of the city, with its own level of technology and land-use patterns, exists in close geographical proximity with other cities of different patterns. This is reflected in the travel and traffic patterns existing in this region. The same road space gets used by cars and buses, along with locally developed vehicles for public transport such as three-wheeled scooter taxis, scooters and motorcycles, bicycles, tricycle rickshaws, animal and human drawn carts. Infrastructure which is designed on the basis of homogeneous traffic models has failed to fulfill the mobility and safety needs of this traffic. Despite low levels of car ownership, accidents and congestion continue to plague this region. This is the right time to question the applicability of models which have been developed for a very different situation.

Traffic Flow and Safety

Two basic parameters of traffic flow which influence the safety of road users are traffic volume or flow measured in terms of number of vehicles per unit time and traffic speed. The amount of traffic, often called traffic flow or more general exposure, is often treated as a matter of routine. Relationship between accidents and flow is, therefore, often assumed to be a simple (linear) relationship. One major reason could be that it seems obvious that an increase in flow leads to an increase in the number of accidents. If we have a system without road users it is obvious that it cannot produce any traffic accidents. And if the number of road users increases this will then obviously lead to increased probability for an accident. Most modelling work has used flow as one major explanatory variable. The most used model structure is the exponential (Ekman, 1996).

$E(A) = k^{*} \text{ exposure}^{y}$ (Kulmala, 1995).

This approach fulfils some basic ideas about traffic and traffic safety: it starts at the origin, zero flow creates no accident. Furthermore, it is monotonically increasing with increasing flow, as long as y is positive. However, this assumption is not completely supported either by basic traffic theory or modern behaviour adaptation theories. The results from estimations based on empirical data is often that y is slightly less than 1. This means that accidents increase by increasing exposure less than a linear approach would have given. This makes intuitive sense also considering the relationship between flow, speed and fatalities.

Flow, speed and fatalities

The standard traffic flow model assumes a parabolic curve between speed and flow as shown in Figure 1.

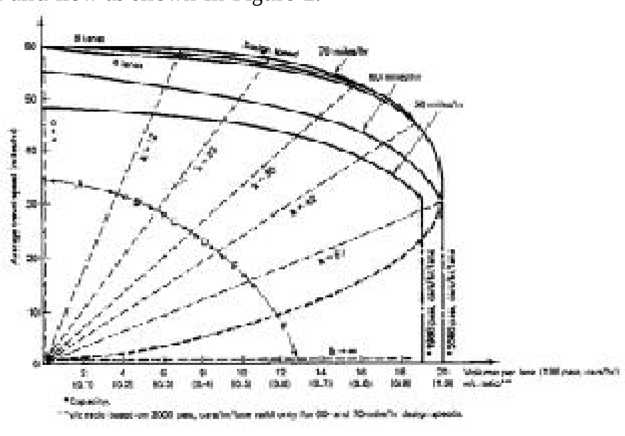

Figure 1 Speed flow relationship (May, 1990)

depending on the degree of heterogeniety in the traffic mix, fatalities and injuries may decrease even if the exposure of vulnerable road users increases

As number of vehicles increase on a network, speed remains constant as long as the flow is below a certain value. This condition is defined as level of service A. Speed reduces gradually until the flow reaches capacity. Consider this relationship with the relationship of speed and fatalities and injuries shown in Figure 2. The estimates for probability of pedestrian deaths at different impact velocities are: 5–8 per cent at 30 kph, 25 per cent at 40 kph, 45–80 per cent at 50 kph, and more than 85 per cent at 60 kph (European Transport Safety Council, 1995; University of Zurich and Swiss Federal Institute of

Technology, 1986.) For car occupants in crashes at 80 kph the likelihood of death is 20 times more than at 32 kph (IIHS, 1987). Clearly, increase in speed is associated with disproportionate increase in number of fatalities. Also, the safe speed for car occupants is much higher than for the pedestrian and bicyclists.

Speed influences energy consumption, pollution, noise, vehicle and road maintenance costs, stress on road users and safety. In general, higher speeds have an adverse influence on all these factors. The safety of road users is influenced both by the absolute speed of vehicles and by the variation in speeds among vehicles on the road (Noguchi, 19**). Other factors remaining constant, higher speeds increase the probability of a crash taking place and the severity of injury in a crash, whereas a greater variations in speeds of vehicles only increases the probability of the event. As illustrated in Figure 2, small reductions in travelling speed result in large reductions in injuries and fatalities in both urban and rural areas. This is because the stopping distance of a vehicle under braking is proportional to the square of the original velocity and the damage to human beings is related to the square of the impact velocity. Lower initial speeds means that the driver has better control on the vehicle and the vehicle can stop much earlier and reduce the probability of a crash. In the event of a crash the injuries are less severe at lower impact velocities.

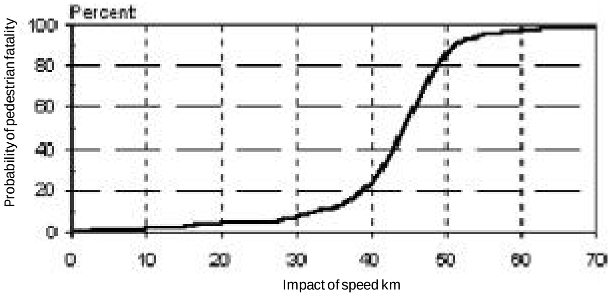

Figure 2 Speed and pedestrian fatalities

The relationship between flow, speed and fatalities requires further consideration in the case of mixed traffic and vulnerable road users. A heterogenous traffic mix has an effect on traffic safety, specially traffic fatalities. Figure 3 shows the distribution of the percentage of non-motorized vehicles (NMV) fatalities versus the percentage of motorized vehicles (MV) trips comprising the location's modal split (Fazio and Tiwari, 1995). Theoretically, no NMV fatalities can result from a striking MV at the origin on the graph because no MVs exist in the traffic stream at this point. When MVs account for 100 per cent of the trips, no NMV fatalities occur because of the absence of NMVs in the traffic. Presence of NMVs also has a calming effect on traffic speed. Data from Delhi also show that as NMV flow increases, the average speed difference between MVs and NMVs decrease specially on roads where mixing of MV and NMV takes place (high conflict between MV and NMV). As the speed difference or initial speed reduces, number of fatalities and injuries reduce. Therefore, depending on the degree of heterogeniety in the traffic mix, fatalities and injuries may decrease even if the exposure of vulnerable road users increases.

Models which predict number of fatalities, injuries and accidents based on a linear relationship with motorization or flow are inappropriate if they do not include speed implications. Rate of fatalities would depend on how the increased flow affects mean speed of the traffic stream as well variation of speed of the traffic stream. The modal diversity present in mixed traffic (primarily in less motorized countries) makes the effect of speed even more critical because the vulnerable road users (VRUs)– people outside cars and buses constitute majority of the victims.

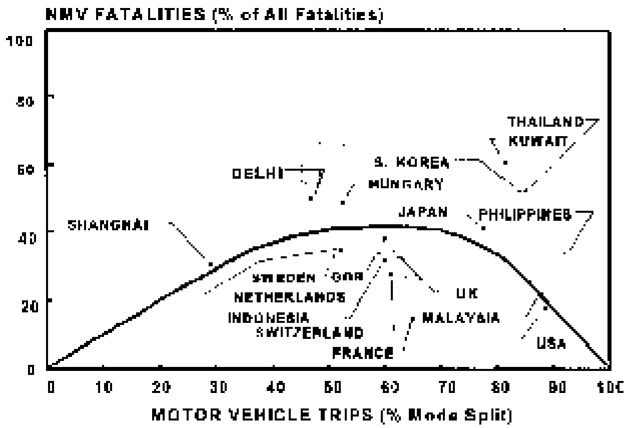

Figure 3 Degree of traffic homogeneity

Heterogeneous traffic Flow: present and future

Nearly 60 per cent of world population lives in developing regions– Africa, Asia and South America (Figure 4).

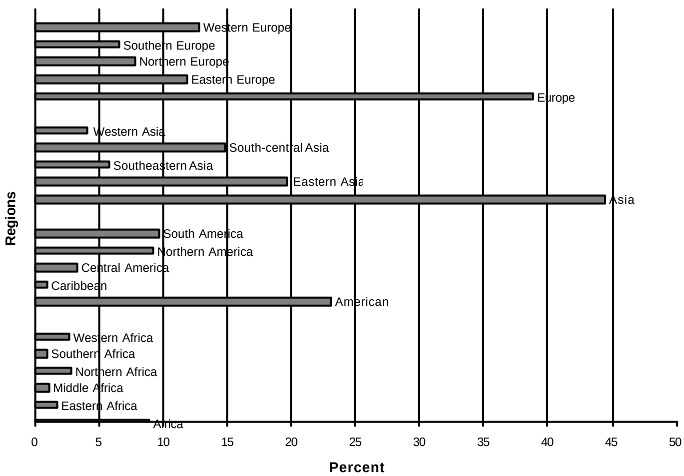

Figure 4 Proportion of urban population in 1990 by region

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These regions are characterized by dominance of large cities–more than 60 per cent of the urban population resides in million- plus cities. Of the 100 largest cities 62 are in this region . A large proportion of the population residing in these cities lives below the poverty line, 29–60 per cent (Figure 5). Therefore, the demand for non-motorized modes and pedestrians on highways and urban areas is inevitable.

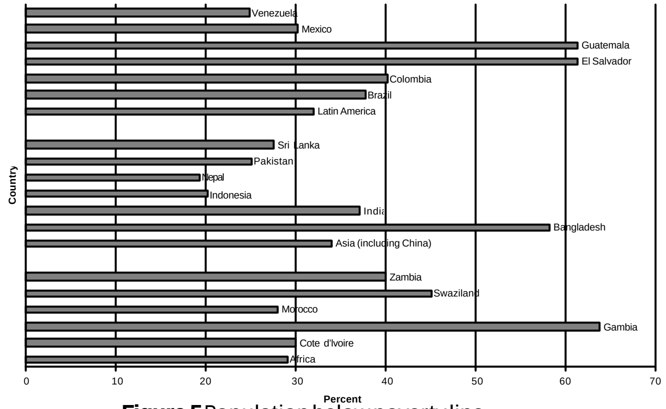

Figure 5 Population below poverty line

Urban areas in developing countries experience such extremes of wealth and poverty that they can be characterized as having dual economies. One serving the needs of the affluent and featuring modern technologies, formal markets, and outward appearance of developed countries. The other serves disadvantaged groups and is marked by traditional technologies, informal markets and moderate to severe levels of economic and political deprivation (Dimitrou, 1990).

Urban poverty, characterized by unemployment, dependence on the informal sector, low wages and insecure jobs, has a direct bearing on travel and transport demand of a large segment of the population residing in urban areas. Their dependence on transport which enables them access to job markets becomes essential for survival. This need is more critical for them than for those with high income and secure jobs. However, this segment of population is also transport poor. Even a subsidized public transport remains cost prohibitive for them.

Cities in developing countries are characterized by heterogenous traffic (mix of non-motorized and motorized modes) and mixed land-use patterns. Non-motorized vehicles are owned and used by a large section of the population (Figure 6).

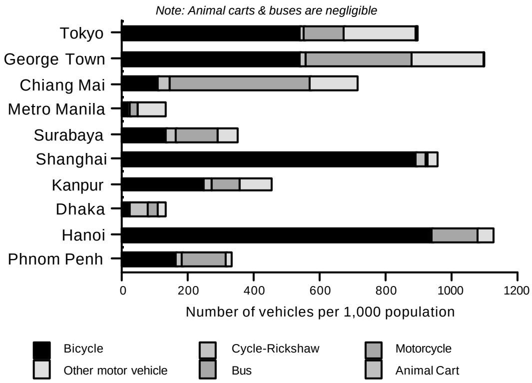

Figure 6 Comparison of vehicle composition

Car ownership rates in Asian countries are low compared to North America and OECD countries. In 1993, it was 29 cars per 1000 residents in East Asian countries compared to 561 cars per 1000 residents in North America, 366 in OECD countries (AAMA, 1995). Although the greatest growth rate in the number of motor vehicles is expected in many Asian countries, most of these increases in absolute numbers of vehicle fleets will result from increases in the numbers of motorized two-wheelers (MTWs) and three-wheelers (World Resources Institute, 1996). In Thailand, Malaysia, Indonesia and Taiwan, two- and three-wheelers account for more than 50 per cent of all motor vehicles.

Non-motorized transport (NMT) constitutes a significant share of the total traffic in many Asian cities. Shanghai, Hanoi, Kanpur and Tokyo all have a relatively high rate of bicycle ownership and a high proportion of bicycle traffic (Figure 7). In Indian cities, the share of NMT at peak hour varies from 30–70 per cent. The proportion of trips undertaken by bicycles range between 15 and 35 per cent, the share tending to be higher in medium and small sized cities. The patterns of NMT use changes with growth in city size. In most NMT-dependent low-income cities, bicycles are used for entire trips (e.g., commuting, shopping). In Kenya, despite several constraints, the NMT including walking are still the prevalent modes that provide more than 45 per cent of all the personal transport in urban centres. In a high-income city like Tokyo, bicycles are increasingly used as a feeder mode to rail stations as well as for shopping and other purposes (World Bank, 1995). Every motorized public transport trip involves access trips by NMT at each end. Thus, NMT including walking continues to play a very important role in meeting the travel demand in cities in developing countr ies.

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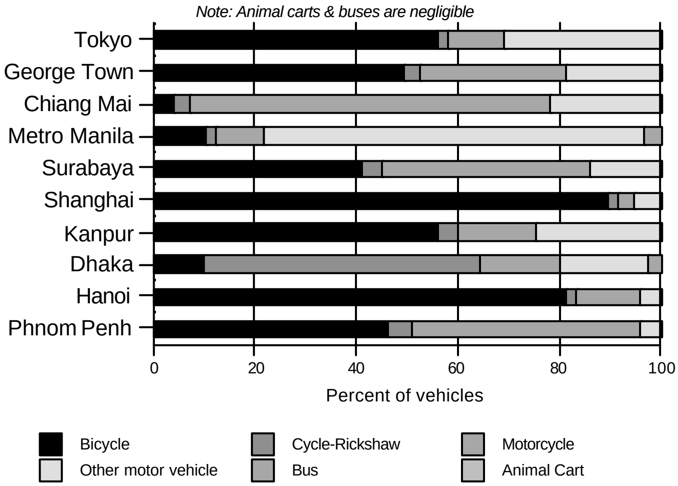

Figure 7 Comparison of vehicle composition among cities

Table 1 gives selected indicators for a few Indian cities. Regardless of city size, it shows that nearly 40–60 per cent of households have monthly incomes of approximately US $50–60. In large cities like Mumbai, Delhi, Chennai, more than 60 per cent of people are employed in the informal sector. For this population walking and bicycling to work is the only mode of transport available. Assuming a minimum of 4 trips per household per day at the cost of Rs 2 (US$ 0.05) per trip by public transport, a household would need to spend Rs.320 (US$ 8) per month on transport. For low-income people living in the outskirts of the city, the cost per trip may be two or three times this amount depending on the number of transfers. On an average, low-income households cannot spend more than 10 per cent of its income on transport. This implies that a household's income must be at least Rs.3200 (US$ 80) to be able to use the public transport system at minimum rates. According to a survey (ORG, 1994), approximately 28 per cent of households in Delhi have a monthly household income of less than Rs.2000(US$ 50).

Table 1
Indian city indicators

Indicator	Mumbai	Delhi	Madras	Bangalore	Lucknow	Varansi	Hubli / Dharwad	Mysore	Gulbarga	Tumkur
Population(million)										
	10.26	8.96	5.65	4.47	1.8	1.08	0.68	0.7	0.33	0.19
Household Income Distribution (Quintile Boundaries US $)										
I (poorest 20%)										
	374	290	347	385	291	268	284	373	258	287
V (richest 20%)										
	2497	3292	2781	2487	2181	2084	2009	2372	1951	1761
Informal Employment(%)										
	68	66	60	32	48	49	31	31	27	63
Motorized Vehicles(per 1000 pop.)										
	51	205	102	130	130	85	49	123	60	63

Data from: Society for Development Studies, Delhi

Survey results show that nearly 60 per cent of respondents find the minimum cost of work trips by public transport (less than Rs.2 per trip) unacceptable (CRRI, 1988). Even at minimum costs, public transport trips account for 20 to 30 per cent of family income for nearly 50 per cent of people living in unauthorized settlements. This segment is very sensitive to the slightest variation in the cost of public transport trips.

The data above show that an estimated 30 per cent of the world population living in urban poverty in cities of developing countries is transport poor. In this segment it is harder for individuals and households to save and build up assets, and reduce their vulnerability to sudden changes/loss in income. Low incomes also make it difficult for households to 'invest' in social assets such as education that can help reduce their vulnerability in the future. Therefore, access to affordable transport is necessary for survival. A sustainable transport system must meet the demand of this captive ridership of non-motorized transport existing in the cities of the South.

URBAN TRANSPORT AND LAND-USE PATTERNS

Heterogenous traffic is likely to continue in less motorized countries (LMCs) because of the socio-economic realities and compulsions. Many cities in LMCs experience such extremes of wealth and poverty that they can be characterized as having dual economies–one for the affluent and the other for the disadvantaged. Very often formal plans address the needs of one set of city residents, failing to recognize the existence of the other set who very often form the majority.

The planning framework as adopted in the preparation of master plans in many Asian cities has been completely divorced from resource assessment. The process also does not invoke any procedures for involving community and bringing about consensus on contentious issues. The net effect of the inadequacies of the planning process has been that majority of urban growth has long taken place outside the formal planning tools. Informal residential and business premises and developments increasingly dominate new urban areas. Even in our megacities where half or more of a city's population and many of its economic activities are located in illegal or informal settlements, urban planners still rely on traditional master-planning approaches with their role restricted to servicing the minority, high income residents. Few weak attempts have been made to bring some coordination of development and 'services' to informal areas through slum improvement schemes.

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Unlike traffic in cities in high income countries (HICs), bicycles, pedestrians and other non-motorized modes are present in significant numbers on arterial roads and intercity highways. Their presence persists despite the fact that engineers designed these highway facilities for fast moving uninterrupted flow of motorized vehicle.

Increase in the level of congestion has been a major concern for planners and policy makers in metropolitan cities. In Delhi average speeds during peak hour range from 10–15 kph in central areas and 25–40 kph on arterial streets (CRRI, 1992). Compared to Delhi, average speeds in other mega cities are less. In 1993, Delhi's traffic fatalities were more than double that of all other major Indian cities combined (*Indian Express*, 1994). Clearly, criteria for recommending optimal speeds and congestion reduction does not include desired level of safety, pollution and land-use patterns.

There is ample evidence to illustrate the mismatch between the careful planning and growing transportation problems. Unless we understand the basic nature of problems faced by our mega cities, the adverse impact of growing mobility on the environment and safety would continue to multiply in future.

The existence of an active informal sector introduces a high degree of heterogeneity in the socio-economic and land-use system. This is assumed to add to our problems of congestion and pollution. However, the informal sector is an integral part of the urban landscape providing a variety of services at low costs, at locations with high demand for these services. Many view hawkers, pavement shops, cycle and motor vehicle repair and spareparts shops as unauthorized developments along the road that reduce the capacity of the planned network. However, since the market demands these services, they continue to exist and grow along arterial roads as well. It is quite clear that long term land-use transport plans must address the needs of the informal sector.

Understanding Heterogeneous traffic flow in developing country cities

Most developing country cities have been classified as 'low cost strategy' cities (Thomson, 1977). In comparison with cities in the West, these cities consume less transport energy. High densities, intensely mixed land-use, short trip distances, and high share of walking and non-motorized transport characterize these urban centres (Newman and Kenworthy,1989) .

Heterogenous traffic flow consists of modes of varying dynamic and static characteristics sharing the same road space. Underlying concepts of traffic flow theory in the US, Europe, and Australia are formed by motorized four-wheel road way traffic dominating in those areas, i.e., homogenous traffic. All car following, lane changing logic and system's measure of effectiveness used in microscopic simulation programmes ultimately use field data from these countries for caliberation.

In LMC cities, the road network is used by at least seven categories of motorized and non-motorized vehicles. Vehicles ranging in width from 60 to 2.6 m, and capable of maximum speeds ranging from 15 to 100 kph, share the same road space. All these vehicles which have varied dynamic and static characteristics share the same carriageway. This traffic is characterized by lack of any effective channelization, mode segregation or control of speeds. To the formally trained planner it looks like chaos moving towards total gridlock. Yet people and goods keep getting through. And may, by some measures actually be doing better than in some controlled conditions.

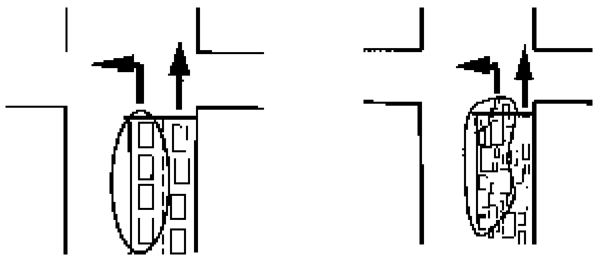
In Delhi different traffic modes are not segregated and there is minimal enforcement of speed limits. In this situation flow patterns result in a natural optimization of road use due to self organization by road users. Though aggregate conflict data do not correlate with fatalities, our data show that Delhi has high number of VRU fatalities. Therefore, segregation and traffic calming techniques developed for Delhi conditions with special reference to motorized two-wheelers are desirable. Techniques developed in HMCs do not address the high volume of motorized two-wheelers and large variations in traffic composition from site to site.

The peak hour motor vehicle flows in traffic with mix of MVs–cars, buses, two-wheeler scooters, three-wheeler scooter– have been observed to be very high compared to homogenous traffic sites of similar street width (Fazio *et al.*, 1998). Having vehicles of narrow widths in the traffic stream greatly increases the capacity of streets. Narrow vehicles fill-in the lateral and longitudinal gaps between wide vehicles; heterogenous traffic uses on-street space more efficiently than homogenous traffic (Figures 8, 9 and 10). Homogeneous traffic flow is modeled on the basis of lane discipline logic. An ideal lane capacity is estimated of only passenger cars by using passenger car units or equivalents.

For heterogenous traffic, having an ideal capacity by lane is mis-conceptual because lane discipline is very loose. Vehicles have varying static and dynamic characteristics.

These share the same road space and move by sharing the lateral as well as the linear gaps. For example, a motorcycle rider judges whether the lateral distance (width) between a motor scooter and bus is acceptable to progress on the roadway. Another motorcycle rider in the same situation would have a different critical width acceptance. If the width is unacceptable, then an entity is constrained by preceding entities. Critical width acceptance depends on three items. First, the travel speed of the vehicle/entity itself. The next item is the physical width of the vehicle. Distribution of the width acceptances of specific entity groups is the third item, i.e., driver/rider/pedestrian behaviour. Each vehicle/entity group has its own critical width acceptance.

Heterogeneous traffic can have many motorized two-wheelers, motorized three- wheelers, bicycles, non-motorized three-wheelers, cars, buses, trucks, animal-drawn carts, and human-powered push and pull carts. Additionally, if sidewalk facilities are inadequate or lacking, this diverse mixture contains significant on-road pedestrian traffic. In homogeneous traffic, traffic entities form one-dimensional queues (Figure 8); in heterogeneous traffic, mass queues develop. These queues grow lengthwise as well as laterally.

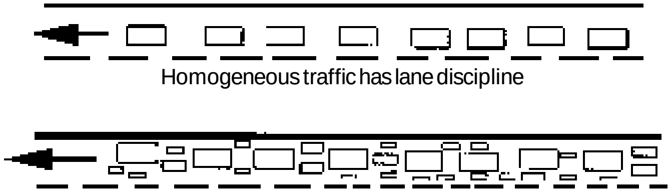


Homogeneous traffic has one dimensional queues — Heterogeneous traffic has two dimensional or mass queues

Figure 8 Queuing theory

Lane discipline is deficient in heterogenous traffic not because driver behaviour is significantly different, but because heterogeneous traffic consists of entities of various widths and varying dynamic characteristics

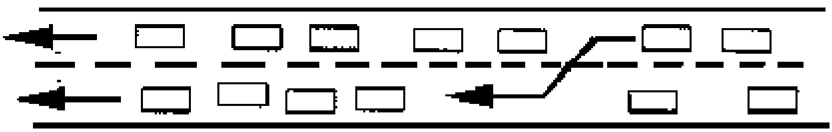
The 'car following' notion used in homogeneous traffic flow models is not applicable in heterogenous traffic (Figure 9). Since cars do not comprise most of the traffic mixture, 'car following' is an incorrect term for heterogenous traffic. Secondly, since width of entities vary greatly in heterogenous traffic, figuring out which leading entity/vehicle it is following is difficult. Leading entities may run parallel or staggered.



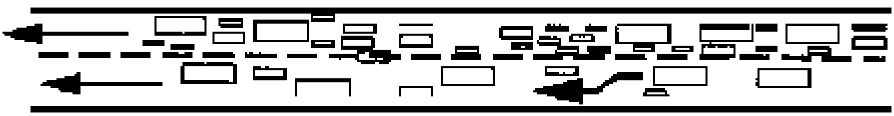
Heterogeneous traffic has parallel/staggered entity-following

Figure 9 Car following

Professionals have extensively derived models and algorithms from the 'lane changing' notion of homogeneous traffic (Figure 10). Microscopic studies of this traffic shows that the time headway between vehicles is an important flow characteristic that affects safety, level of service, driver behaviour and capacity of a transportation system. A minimum time headway must always be present to provide safety in the event that the lead vehicle suddenly decelerates. The percentage of time that the following vehicle must follow the vehicle ahead is one indication of level or quality of service. The distribution of time headways determines the requirement and the oppurtunity for passing, merging, and crossing. The capacity of the system is governed primarily by the minimum time headway and the time headway distribution under capacity-flow conditions.



Homogeneous traffic uses lane concept



Heterogeneous traffic uses width acceptance/entity envelope

Figure 10 Lane changing

Clearly, underlying these concepts is the notion of lane discipline or lack of it. Lane discipline is deficient in heterogenous traffic not because driver behaviour is significantly different, but because heterogeneous traffic consists of entities of various widths and varying dynamic characteristics. With homogeneous traffic, the width range is approximately 2.1 m for cars to 2.6 m for trucks and buses. Homogeneous traffic drivers find it optimal and advantageous to adopt lane discipline to traverse the roadway space given the narrowness of the width range. For heterogeneous traffic, the width range is approximately 6 m for pedestrians to 4.9 m for overburdened truck trailers. Drivers, pedestrians, riders and animals find it optimal to advance by accepting lateral gaps (widths) between preceding entities. Heterogeneous traffic uses road space more efficiently than homogenous traffic. For this traffic, models based on width acceptance can ultimately produce a good estimate of roadway capacity and assessments of operations and safety of various facility designs.

This specific characteristic of heterogeneous traffic highlights the limitations of conflict technique which has been developed for homogeneous traffic (Tiwari G *et al.*,1998). There are very few detailed studies on traffic patterns and their influence on accidents in LMCs. We use here a study conducted in Delhi which involved conflict analysis for prediction of fatal crash locations. Peak hour traffic at fourteen selected locations were videotaped. Trained observers recorded traffic compositions at mid-block, average space, mean speeds by mode and conflicts by type, reactor mode and cause mode. The study showed a weak crash-conflict association. Definitions of conflict developed in HMCs where motorized vehicles are the dominant modes are inadequate in heterogeneous traffic situations like Delhi. In heterogeneous traffic streams, bicyclists, motorized two-wheelers and motorized three-wheelers have the freedom of moving laterally as well. These manoeuvers at low speeds need not necessarily lead to fatal crashes. Kouabenan (1996) and Salimen *et al.* (1992) have also reported that fatal accidents generally differ in causation from non-fatal injuries. The 3.5 metre wide lanes designed to fit four-wheeled motorized vehicles, such as cars, trucks, and buses can fit at least two lanes of two wheelers. These space sharing manoeuvers of heterogeneous traffic are also recorded as conflicts. These manoeuvers at low speeds need not necessarily lead to fatal crashes. For mixed traffic, we need to develop better understanding of conflicts to differentiate between conflicts that are a part of normal driving cycle and the ones that are potential crashes.

These issues convince us that LMCs are experiencing a new phenomenon in road traffic patterns and accidents for which there is little precedence. These patterns are new and they need to be understood through careful scientific research.

Safety in Heterogeneous traffic

The proportion of road users killed in various modes of transport as a percentage of all fatalities in different countries is shown in Figure 11. The data show that non-car occupants constitute almost 75 per cent or more of all fatalities in most developing countries. This flows logically from the fact that this class constitutes the majority of road users however, roads and other transport infrastructure designs address the need of motorized vehicles only. In addition, because VRUs are not protected by metallic or energy absorbing materials, they sustain relatively more serious injuries even at low velocity crashes.

In many LMCs highways run through rural areas with high density populations where most people do not have access to motor vehicles.

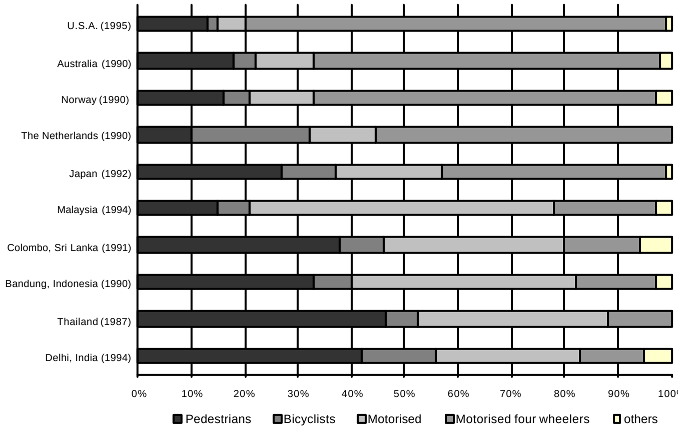


Figure 11 Proportion of road users killed in different countries

It is possible that wherever the proportion of VRUs is high as a proportion of all road users similar crash rates will be experienced as in India. However, some less motorized countries (LMCs) do not have bicycle use rates as high as those of countries like India, China and Vietnam, and these countries have lower involvement of bicycle fatalities (Tiwari and Saraf, 1997). In these countries where bicycle use rates are lower, it appears that MTW and pedestrian fatality rates are proportionately higher. Data show that in most developing countries, the urban poor who are heavily dependent on NMVs, are the victims of road traffic crashes.

Almost 80 per cent of all cars are owned by 15 per cent of the world's population residing in North America, western Europe and Japan. On the other hand, in LMCs like India and China, less than one in a hundred families owns a car. Car ownership levels in LMCs are so low that even at a reasonable economic growth rate (say 7–10 per cent per year) for the next few decades, most families in LMCs are not likely to own a car in the next quarter of a century. A comparison of per capita levels of vehicle registration and proportions of cars and motorcycles in a few countries is given in Table 2. These ownership patterns show that total vehicles registered per capita, and car and motorcycle ownership levels differ greatly in HMCs and LMCs. These different ownership levels influence traffic behaviour patterns and composition of traffic fatalities.

Table 2
Vehicle Registration and Proportions

Country	GNP per capita US $	Total number of vehicles /1,000 persons	MTWs as % of total vehicles	Cars as % total vehicles
Japan	34 630	640	20	58
USA	24 780	740	2	88
Germany	23 980	570	9	89
France	23 420	520	10	87
UK	18 340	410	3	86
Australia	18 000	610	3	76
Republic of Korea	8 260	206	24	33
Malaysia	3 140	340	56	34
Thailand	2 410	190	66	16
Philippines	950	32	26	28
Indonesia	810	58	69	15
Sri Lanka	600	50	60	13
China	530	21	40	24
India	320	30	67	14
Vietnam	210	27	91	9

These figures suggest two different phenomena that are relevant to road safety policies. It appears that total vehicle registration levels remain below 100 per thousand persons in countries that have per capita incomes of less than US $ 1,000 and that motorcycle registrations decrease below 20 per cent of the total vehicle fleet only when per capita incomes are much greater than US $ 8,000. The only exceptions are countries like China where MTW production or availability has been controlled by government policy. Even at per capita income levels of US $ 3,000 car ownership levels remain low and the proportion of MTWs can be more than 50 per cent. Most LMCs, including India and China, will not reach per capita income levels of US $ 3,000 in the next decade. As incomes increase, the poorest people in countries like India and China will be able to own bicycles and those who own bicycles today may opt to buy motorcycles when they become richer. As the number of poor and lower middle class people in these countries is larger than that belonging to the upper class, we are likely to witness greater increases in absolute numbers of bicycles and motorcycles than cars in the next decade or so. Road safety policies and countermeasures that are based on societies where car fleets constitute about 80 per cent of the vehicle fleet will not be adequate for most LMCs where MTWs comprise more than 40–50 per cent of the total number of vehicles.

The prevalent high rates of pedestrian, bicycle and motorcycle traffic in LMCs (proportions do differ from country to country) result in VRU fatalities constituting 60–80 per cent of all traffic fatalities (Mohan, 1992). These patterns of traffic and accident in LMCs are not only different from those that are prevalent in HMCs today, but are also different from the experiences of HMCs in the past. The HMCs have never experienced road traffic that includes such a high proportion of motorcycles, buses and trucks sharing the same road space with pedestrians and bicyclists. In addition, in the earlier part of this century when the present HMCs had low per capita incomes, motor vehicles (including motorcycles) were relatively more expensive and not capable of high velocities and accelerations. Therefore, speeds were lower and number of vehicles using roads was less than that seen today. In a sense, motor-vehicle technology, roadway quality and social systems were more compatible. On the other hand, LMCs now have to plan for use of technologically advanced vehicles using relatively ‘less advanced’ roadways and enforcement systems.

future traffic models must account for the users of different transport modes having conflicting requirements… Highway planning standards provide for services needed by motorized vehicle users. However, there are no standards for providing services needed by NMT

Because bicyclists and pedestrians continue to share road space in the absence of infrastructure specifically designed for NMVs, they are exposed to higher risks of being involved in a road traffic accident by sharing the road space with high speed modes. Unlike cities in the West, pedestrians, bicyclists and MTWs constitute 75 per cent of total fatalities in road traffic crashes. Buses and trucks are involved in more than 60 per cent of fatal crashes. Buses are often very crowded inside and significant proportion of passengers who die are those who fall from footboards of buses. In addition, many indigenously designed vehicles (IDVs) such as tempos, *jugar* are present on roads of Indian cities because of the absence of efficient and comfortable public transport services. These IDVs operate as paratransit modes thus serving a useful role in the context of existing social system (Tiwari, 1994).

In HMCs a very large proportion of the population owns motorized vehicles. In addition, these countries can afford to have roads parallel to expressways to be used by local traffic and vehicles not allowed on expressways. In many LMCs highways run through rural areas with high density populations where most people do not have access to motor vehicles. Also, many expressways in LMCs do not have parallel road links for slow and non-motorized traffic. This forces slow and non-motorized traffic to use expressways and to cross them illegally where that majority of the victims of road accidents on intercity highways are the vulnerable road users.

FUTURE DIRECTIONS

Various road users have different and often, conflicting requirements. Motorized vehicles need clear pavements and shoulders, while bicyclists and pedestrians need shaded trees along the pavement to protect them from the summer sun. Owners of private transport modes like MTW and automobiles prefer uninterrupted flow, fewer stops and minimum delays at intersections, whereas public transport buses require frequent stops for picking and discharging passengers. Motorized four-wheeled vehicles like cars, buses, etc., perform better if they move in queues with minimum braking and acceleration. Since our infrastructure design does not account for the existing conflicting requirements of different modes, all modes have to share the road space and operate in sub-optimal conditions.

Experience of past decades of long-term integrated land-use transport plan exercise suggests that the existence of informal sector and their travel needs must be recognized for preparing effective plans. This should encourage mixed land-use patterns and transport infrastructure especially designed for bicycles and other non-motorized modes.

Future traffic models must account for the users of different transport modes having conflicting requirements. These models must account for the needs of motorized vehicles for clear roads for uninterrupted traffic flow, at the same time they must address the needs of bicyclists and pedestrians for shady trees, kiosks for drinks, food and bicycle repair shops, etc., at shorter distances. Highway planning standards provide for services needed by motorized vehicle users. However, there are no standards for providing services needed by NMT. These services mushroom along urban or inter-city highways to fulfill the demand of road users, however their existence is viewed as 'illegal encroachment' on the designed road space.

Motorized vehicles are designed to operate at much higher speeds for better fuel economy and emission levels. Roads are also designed to increase throughput of motorised vehicles only. These measures decrease safety of NMV occupants and pedestrians sharing the same road space. Therefore, safe facilities–segregated lanes, convenient crossing opportunities from the point of view of NMV users should form an integral part of the road designs. At present these facilities are viewed as cost increasing measures which many developing countries cannot afford due to resource crunch.

Urban streets passing through the commercial development and highways passing through small towns serve multiple purposes. They carry through traffic.

However, the adjacent land-use generates cross-traffic and demands multiple space usage, for example, space for parking vehicles, space for hawkers and informal shopping, etc. The existing design standards do not account for conflicting demand between local traffic and through traffic resulting in sub-optimal conditions, i.e., long delays for through traffic and safety hazards for local traffic specially at off peak hours, for both kinds of traffic.

We have to accept the fact that safety has to be promoted in most LMCs within existing conditions. These include low per-capita incomes, presence of mixed traffic, low capacity for capital intensive infrastructure and different law enforcement capabilities. This approach will be important for most LMCs as they are not likely to experience economic growth rates which puts them at par with HMCs within the next couple of decades. This implies that pedestrians, bicyclists and motorized two-wheeler (MTW) riders will remain dominant on LMC roads for many decades. This group of road users will be called the vulnerable road users (VRUs).

Such traffic systems are very complex and will need new understanding. Therefore traffic flow and safety models need to developed for this complex traffic to meet their specific requirements not found in homogenous traffic conditions.

A major shift is required in design principles itself to promote safety in LMCs. If a large number of users are pedestrians, bicyclists and other slow moving vehicles then road designs have to address their needs in addition to the needs of motorized vehicles.Motorized vehicles can use a longer route and over-bridges, however, a pedestrian or bicyclist would prefer not to use an underpass or over-bridge just because it is safer to do so. For this group of users convenience is an overriding priority.

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There is a need to accommodate the conflicting requirements of NMV occupants and pedestrians, and motorized traffic on our urban and inter-city highways. This includes redesigning the road cross section setting more exclusive space for pedestrians and NMVs ,and giving pedestrians and bicyclists priority over cars at certain places.

Speed control is perhaps the most important measure for reducing road traffic crashes in LMCs. Methods to control speed in urban and residential areas should be given the highest priority. Currently we do not have a good understanding of how this can be done at low policing levels in the traffic mix seen in LMC urban areas. For rural roads there are no good designs for non-expressway safety with high VRU participation.

The quality of roads issue has to be addressed in terms of providing better facilities to non-motorized road users, developing suitable designs for heterogenous traffic and those for slowing traffic in residential areas. In many LMCs even on national highways, majority of people killed are pedestrians, bicyclists, those using two-wheelers or involved in crashes with tractors/bullock carts. Therefore, unless these issues are addressed and methods developed for area wide safety improvements we will not be gaining much by concentrating on blackspot treatment.

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