Heterogeneous Traffic Mixes

Donny Katz
CEE 6603 – Term Paper
Date Due: November 18, 2009

ABSTRACT

A heterogeneous traffic stream consists of vehicles that have different speeds, sizes, operating characteristics, and vehicle spacing. Homogeneous design methods do not fit the heterogeneous situation, especially in non-lane-based roadways that populate the developing world. This paper reviews the status of heterogeneous mixes worldwide, and what factors need to be considered in such mixes. The issues of safety, modeling, and non-motorized transport are considered, and solutions for these are discussed. These are important because the need for an understanding of heterogeneous mixes will grow in the future due to their presence in developing world megacities and growth in the developed world.

INTRODUCTION

The real world does not always consist of a stream of uniform vehicles. A homogeneous traffic stream makes many calculations much simpler because vehicles' size, speed, and following distances can be held constant. This allows for changes in other variables without the worry of confounding. Heterogeneous traffic mixes do not provide this luxury, with a variety of vehicles interacting within the traffic stream. The objective of this paper is to examine the flow characteristics of heterogeneous traffic mixes and their effect in the developing world[1].

CONTEXT

A homogeneous traffic mix has no variation in the operating speeds, size, and driving character of its vehicles. In the real world this is not unheard of. Some highways do not allow truck traffic, and the resulting traffic stream is entirely composed of passenger cars and light trucks. A truck-only toll facility would similarly only consist of a homogeneous mix of heavy trucks. A heterogeneous mix is the opposite situation, when vehicles of all shapes and sizes interact on the roadway, often with different operating characteristics and speeds.

The dividing line between homogeneous and heterogeneous is not clear cut. Do a few motorcycles traveling amongst a passenger car stream suddenly cause it to be labeled heterogeneous? Does one truck affect a mix significantly, or is there a certain level up to which the effect of trucks' size and acceleration difference are not felt? Studies have recommended a cut-off below which traffic streams cannot be assumed to operate homogenously. Arasan and Krishnamurthy (2008) suggest heterogeneous traffic mixes to exist when the percentage of the dominant mode is less than 80% of the traffic mix, while Fazio, Hoque, and Tiwari (1999) suggest the value to be slightly higher at 85%. This cut-off is rough, and there is not a dramatic change immediately below and above it. The impact though, once one decides a mix is heterogeneous, is certain assumptions that can be applied to homogeneous mixes become irrelevant. These can include lane discipline, assuming a passenger car equivalent (PCE) value for vehicles in the stream, and vehicle-following characteristics.

The scope of this paper is restricted to heterogeneous traffic mixes as they apply to the developing world. Although there are certainly many developed regions where heterogeneous traffic exists, even in North America, the paper is focused on the situation worldwide where vehicles do not abide to lane discipline, intersections are not always properly controlled, and a wide array of locally developed vehicle types use the roadway.

Heterogeneous Mixes: Where and When

Traffic mixes over time have fluctuated between homogeneous and heterogeneous. The factor through history pushing the shifts has been the availability of new technology and the income of the population to be able to afford one mode over another.

In developed countries, mixes have already shifted from homogeneous, to heterogeneous, back to homogeneous, and are starting to return to heterogeneous again, if not already there. The original traffic mix consisted entirely of pedestrians, with only animal-pulled carts and wagons sparsely included. As different modes came into being and technologies became increasingly affordable, traffic became more heterogeneous. Bicycles increased mobility for a low price, streetcars became part of the traffic mix, and different methods of transporting goods showed up. The automobile, ultimately, caused a major shift back to homogeneity, and within a few decades, other means of getting around became afterthoughts in mode choice decisions. A shift back to heterogeneous mixes in developed countries is occurring in the modern day due to increased attention to energy expenditure, freight movement by trucks, and public transit.

---

[1] In this report, "developed country" is synonymous with high-income countries such as those in Western and Northern Europe, Japan, Australia, and the U.S. and Canada. "Developing country" is synonymous with low-income countries, and refers to East and Southeast Asia, Africa, South America, and for a significant part of the report, South Asia,

Developing nations have not followed this pattern. These regions followed the first two steps in mix shifts that developed nations took, but average low incomes inhibited a shift to the private automobile. Motorization occurred slowly, and still is of low penetration even in large megacities. In East Asia, there are 29 cars per 1000 residents; this figure rises to 561 in North America (Tiwari, 2000).

Barter (2000) describes the motorization process as it occurred in Asia, outside of Japan, in the latter half of the twentieth century. High-density cities were already operating with mixed traffic in the 1940s through the 1960s: bus and jitney services provided mobility for longer trips, non-motorized transport (NMT) for trips under five kilometers, and low cost taxi services provided the feeder routes for buses. Then motorization occurred and problems multiplied. Over the next five decades, countries in Asia began to motorize one-by-one. The mix that resulted from the motorization process was more heterogeneous than before, but now consisted of fast-moving cars. Suddenly there was a safety issue for NMT and a cry from those with cars to provide clear roads. When these cities started motorizing, their dense nature (developed countries motorized with cities at much lower densities) did not fit the desires of owners to travel far and fast. Lastly, most of these cities did not have traffic-segregated transport, such as a rail system. Even just a small percentage growth in private vehicles in developing countries put immense strain on their networks.

Current Traffic Mixes

Each country in the developing world has evolved a unique mix of traffic. For example, South Asia's heterogeneous traffic mixes are heavily populated with three-wheel autorickshaws, cycle rickshaws, and buses. Southeast Asia has developed a culture of two-wheel motorbikes, and in many places, a motorbike is much more preferred than cars.

Income levels are the most significant explanatory variable as to why certain cities motorize or not, although propensities to certain types of vehicles have resulted from a product of culture and availability of technologies. In Dhaka, located in one of the poorest nations in the world, NMT is the dominant mode, and cycle rickshaws flood the city. In India, NMT still comprises 30-70% of traffic in the peak hour. Even Japan, the most developed country in East Asia, has high bicycle usage in feeding its transit station (Tiwari, 2000). The different traffic compositions for various developing cities are shown in Figure 2.

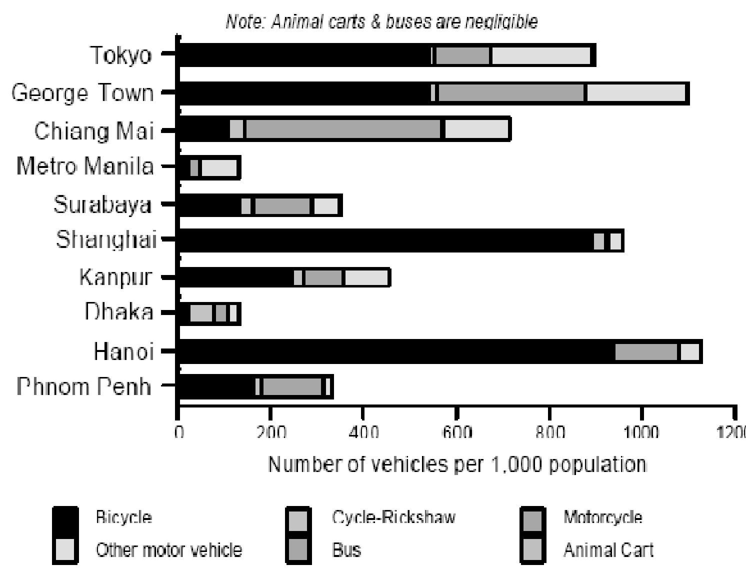

Figure 1: Comparison of developing megacities' traffic composition.

Importance of Understanding Heterogeneous Mixes

Heterogeneous traffic mixes cannot be engineered using the same techniques that are necessary for homogeneous traffic mix analysis. As described by Tiwari (2000), "infrastructure which is designed on the basis of homogeneous traffic models has failed to fulfill the mobility and safety needs of [heterogeneous] traffic" and the situation is dire. The developing world is particularly having issues planning for the traffic mixes on its streets. "Despite low car ownership, accidents and congestion continue to plague this region," and with more than half of the world's population residing there, it is of utmost benefit to society to plan for it. Managing vehicle interactions is critical for countries with heterogeneous traffic mixes.

To understand how heterogeneous mixes operate will shed light on how to plan for them in the future. Models in the past attempted solely to represent traffic mixes through a conversion to an equivalent number of passenger cars. This has historically misrepresented what occurs in real life. Different steps must be taken to design streets for mixed traffic, and the models used in design and operation planning must represent the differences that exist.

TRAFFIC STREAM CHARACTERISTICS

Heterogeneous traffic mixes do not operate the same as homogeneous mixes, and for this reason, researchers have sought to understand the traffic stream characteristics as they apply to mixed traffic. In these situations, speed, flow, and density are understood differently, and sometimes need different parameters to describe them.

Heterogeneous Traffic Streams

A heterogeneous mix may consist of many different types of vehicles each with its own physical and operational characteristics.

Lane Discipline and Vehicle Following

In developing countries, it is not uncommon for roadways to be constructed without lane lines or for vehicles to disregard those that exist (Khan and Maini, 1999). Effectively, each vehicle can make use of the entire road without being restricted to a defined path on the road. There is a significant amount of lateral movement within the right of way. Gowri and Sivanandan (2008) take this into account in their models, and account for the whole roadway at once. Heterogeneous traffic mixes also do not have the presumption that vehicles will follow each other single-file. The one-dimensional queues of homogeneous mixes become mass queues that operate two-dimensionally in heterogeneous traffic (Tiwari, 2000).

Vehicle Movement Characteristics

The traffic stream's diverse array of vehicles do not all travel at the same speed, nor accelerate at the same rate. Dey, Chandra, and Gangoapahyay (2008) explored the mean, maximum, and minimum speeds of vehicles in a traffic stream. There were drastic differences between motorized vehicles and NMT, but also amongst the various motorized modes. Acceleration and deceleration characteristics for vehicles are also important, and knowing these aids in modeling mixed traffic streams and the interactions between vehicles (Gowri and Sivanandan, 2008; Mallikarjuna and Ramachandra, 2006b; Arasan and Krishnamurthy, 2008).

Size

The varieties of vehicles in the traffic stream all have physical size differences. The length and breadth of vehicles determines where and how the vehicle can navigate in the traffic stream. Because of a lack of lane discipline, vehicles of smaller size can fit between tighter gaps and make more efficient use of roadway space. Several studies have evaluated vehicle sizes and used these in their models (Arasan and Krishnamurthy, 2008; Mallikarjuna and Ramachandra, 2006a), especially to capture the effect of two-wheelers and bicyclists making their way to the front of queues because of their ability to fit between larger modes.

Separation Distances

Vehicles within a heterogeneous traffic stream also vary by their longitudinal following distances and lateral spacing. Gowri and Sivanandan (2008) evaluated each mode's following distance when stopped based upon which other mode it was following. These changed for each combination. For example, a light commercial vehicle stayed 0.73 m behind a motorbike, but 1.5 m behind a truck. Longitudinal following distances affect the spacing of traffic, and are reflective of the comfort of a driver and their confidence to stop their moving vehicle. Each mode has unique values for spacing, based on deceleration rates.

Lateral clearances also are key factors, and vary by speed and mode. The gaps that exist between vehicles may be suitable for some modes to navigate through, but restrictive for others. Motorbikes not only can accept narrow gaps in the traffic stream, but also are more willing to get closer to other vehicles when passing. Arasan and Krishnamurthy (2008) list the tolerances of different modes' lateral clearances at both stopped and moving conditions.

Driving and Stopping Patterns

The vehicles in mixed traffic also differ in how they operate. Even amongst similar sized vehicles there can be major differences. Amongst a stream of cars, some may be taxi services that may make unexpected stops to pick up passengers. Not all buses operate the same way: some may dwell longer at curbs than others or stop more frequently. Within a traffic stream with mixed sizes and movement characteristics, not all vehicles operate in the same manner.

Speed

The average speed of the traffic stream is determined by the many factors of each vehicle; the heterogeneous traffic stream operates neither smoothly or as a whole. There are variations occurring across the road width, and these differences are unable to be modeled with one speed for the entire stream.

Often, it is necessary to have microscopic observations to describe the speed of various modes. Khan and Maini (1999) report that faster vehicles are forced to drop their speeds in heterogeneous traffic mixes as density increases, while slow vehicles actually increase their speed. This occurs because the various modes come to a speed equilibrium as the road fills up; the faster vehicles cannot go any faster than the slowest ones. In addition, it was also noted that slower vehicles actually increase their speeds with increased density, believed to be related to safety as they attempt to match the speed of traffic.

This effect was also noted by Arasan and Krishnamurthy (2008), but they additionally saw that the average speed of the traffic stream itself decreases. They attributed the changes to decreases in longitudinal and lateral clearances as the vehicles became more crowded under higher volumes, making faster vehicles hesitate to increase their speed.

Flow

Due to the lack of lane discipline in most heterogeneous contexts, flow cannot be expressed as it is in lane-based systems, typically in vehicles per hour per lane. Arasan and Krishnamurthy (2008) describe how the whole width of the roadway is necessary to express flow. The interactions laterally between vehicles have a large effect of a road's capacity. But size of the vehicles in a heterogeneous mix, unsurprisingly, is just as important. A higher proportion of two-wheeled motorbikes increases flow because the smaller vehicles make more effective use of roadway space, while larger heavy vehicles decrease a road's capacity (Dey et. al., 2008).

Density

The density of heterogeneous traffic mixes is difficult to represent because of the lack of lane discipline and the different sizes of vehicles. Unlike with homogeneous flows which employ a linear density by lane, this measure becomes useless in a non-lane-based heterogeneous flow. Khan and Maini (1999) make the claim that in an uninterrupted facility, areal density is the best operational characteristic to define conditions of the flow. Mallikarjuna and Ramachandra (2006a) propose area occupancy as the solution to representing the density of heterogeneous traffic mixes. They reason that measured over time, area occupancy is meaningful because it considers that varying vehicle dimensions of heterogeneous traffic.

Area occupancy expresses for how long a particular size vehicle is moving on a section of the road. Measured over space, as $\rho_A(s)$, it is the sum of all vehicle areas divided by the road width and length. Measured over time, as ρ_A, it is described as a three dimensional representation of occupancy, with the width of the road being the third dimension beyond detector length and time.

$$\rho_A(s) = \frac{\sum_i a_i}{W \times L} \qquad \rho_A = \frac{\sum_{i=1}^{N} O_i \times w_i \times d}{T \times W \times d}$$

In the area occupancy space equation, a_i is the area of a vehicle W is the width of the road, and L the length of road section under consideration. In the area occupancy time equation, O_i is the occupancy time of the i^{th} vehicle, w_i its width, d is the length of road under consideration (same as L in the space equation), T is the observed period, and W is the width of the road.

PCE Values

PCE values are the historical way of handling mixed traffic. In homogeneous traffic, this technique is commonplace, and is performed to simplify the effect of the few vehicles that are different. It is heavily debated whether using PCE values is appropriate for modeling heterogeneous flow.

In one camp, it is argued that PCE values are the best way to convert all vehicles into usable information for modeling traffic. Arasan and Krishnamurthy (2008) prefer the PCE technique, using the values in simulation by replacing half of the cars in a homogeneous flow with a certain amount of another vehicle type until the homogeneous average speed is achieved. The amount of the introduced vehicle, divided by the cars replaced, is the PCE value. They found that PCE values changed based on the volume of traffic, and thus reported with their corresponding traffic volumes. At low volume levels, there is an increase in PCE values as traffic volume increases, due to high levels of impedance in the traffic flow due to a dissimilar mode. At higher volumes though, PCE values begin to decrease with volumes, as the impeding effect on the stream is reduced.

Dey, et. al. (2008) agrees that PCE values are useful. In their study, they found that most vehicle categories have PCE values that decrease with increases in the vehicle's proportion in the traffic stream. The only exception was heavy vehicles, which had increases in PCE values as the proportion of them increased. They also found that at higher volumes, interactions between vehicles increase, and speed differentials decreases between all modes, effectively reducing PCE values since vehicles are then more similar operationally. Mallikarjuna and Ramachandra (2006b) agree with this, and found the same nature for PCE values. Ultimately, it is seen that PCE values for modes are greatest when at low proportions as their effects are unique amongst the traffic flow, causing greater disturbances.

The other camp argues that microsimulation is the only assured way to capture the full nature of each vehicle's independent characteristics, and the PCE conversion step must be skipped. Khan and Maini (1999) consider PCE values unacceptable and not applicable to heterogeneous traffic mixes. Instead, they would rather see traffic composition and degree of saturation as the major inputs. To do this, it is necessary to collect accurate speeds and area occupancy. Even though Mallikarjuna and Ramachandra (2006b) support PCE values, they acknowledge the difficulty in attaining them under dynamic traffic conditions, and that may be reason enough to avoid them and focus more on area occupancy.

ISSUES WITH HETEROGENEOUS MIXES

Modeling Heterogeneous Traffic

One of the large issues with heterogeneous traffic is the lack of tools for designers to properly model and accommodate multiple modes. Several of the studies in this report undertook the endeavor of modeling heterogeneous flow through microsimulation because they saw the lack of understanding of such flows in past research (Arasan and Krishnamurthy, 2008; Dey et. al., 2008; Mallikarjuna and Ramachandra, 2006b). This deficit of understanding of heterogeneous traffic mix movements caused designers to design facilities as if they consisted of homogeneous mixes, because there were no suggestions otherwise. The new literature provides techniques and models that are representing heterogeneous mixes appropriately, and suggestions on how to design for roads and intersections that are without lane discipline. New computerized methods of simulating traffic are perhaps the greatest step forward for heterogeneous mixture planning.

NMT Issues

For many countries, NMT is the predominant mode type and is the means of mobility for the majority of the population. Thoughts on NMT are divided. Fazio et. al. (1999) warns about removing or restricting access to NMT from city streets (a policy move implemented in many megacities), describing that doing so reduces the maximum capacity on the urban street system. It also brings the traffic composition to a more hazardous traffic mixture, one composed of more fast moving vehicles. Wei et. al. (2003) disagrees, and believes that NMT causes serious congestion and a reduction of capacity at urban intersections. The swarming nature of NMT causes a breakdown of flow, and they believe such modes should be banned from the center of intersections. Ultimately, the goal is to put priority on motorized vehicles.

One of the issues regarding NMT is where they travel on the roadway. Gowri and Sivanandan (2008) make the assumption in their model that NMT keeps to the outside edge of the facility. This holds fairly well until the proportion of NMT is higher, and traffic speeds reduce to match the pace of the slower NMT. At this point, these slower modes become more integrated in the traffic stream.

Regardless of the level of NMT in the mixture, Brar and Chopra (2008) describe the issues at intersections, where some turning NMT stays to the outside lane, while others cut to the middle of the road to avoid conflicts with through traffic (Figure 2). This creates conflict points in the intersection though with both straight and turning traffic, and NMT dominates the intersection. They recommend separating the turning and through movements in phasing of the intersection to reduce these conflicts.

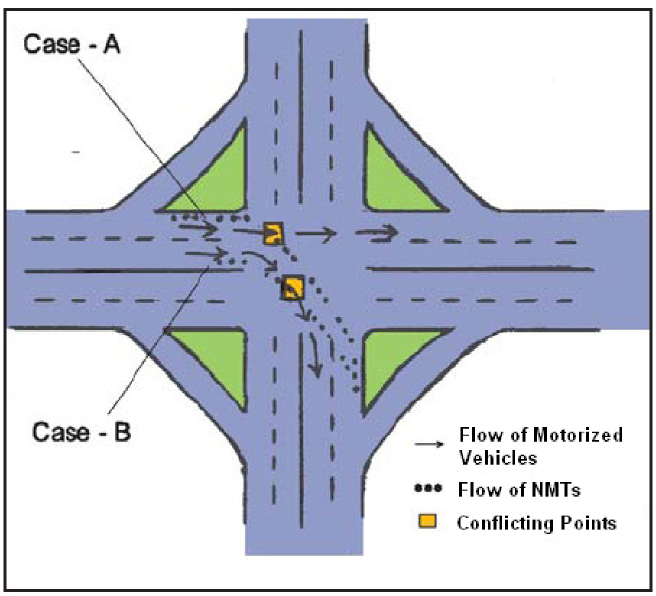

Figure 2: Simultaneous turning movements of motorized vehicles and NMT, with conflict points between the travel paths.

NMT is often considered to be encroaching on a highway by city planners, and this mindset needs to shift. Tiwari (2000) describes how infrastructure designed specifically for NMT will reduce traffic fatalities and improve flow. This means maintaining those facilities as well; pedestrians already are forced to walk in the street because sidewalk space has been scooped up by streetside businesses. The argument is that the road cross section should provide more exclusive space to NMT and pedestrians, especially because they are the dominant mode in many megacities and deserve priority.

Safety

Heterogeneous traffic mixtures have unique safety issues that are not typically seen in homogeneous mixtures. These unique issues are mainly due to the interactions between vehicles and the disparity in speeds and sizes. They have been the cause for much study and have led to countermeasures specific to heterogeneous mixes. Fazio et. al. (1999) describes though how the largest issue facing heterogeneous traffic users is that the facilities are often designed for a homogeneous mix, as there has been a lack of resources to lead road designers down a different path.

The mix of traffic is the largest determinant of traffic fatalities. Tiwari (2000) documents how the proportions of NMT and motorized vehicles in a traffic mix are related to the number of NMT fatalities. It was seen that countries which had levels of homogeneity between 30 and 80% had the highest level of NMT fatalities. Exposing vulnerable road users, such as NMT, in proximity to higher speeds unavoidably causes conflicts. It is not surprising that developing countries' vast majority of fatalities and injuries are from pedestrians, bicycles, and motorbikes (Mohan, 2002).

The composition of higher-speed vehicles in the mixture can cause drastic differences in fatality rates. Fazio et. al. (1999) report 1900 fatalities for New Delhi, which has a population of nine million. Dhaka, with a similar population of seven million, only had 300 fatalities. The authors attribute this to the higher motorization rate in New Delhi, with many motorbikes and cars, while Dhaka is predominantly cycle rickshaw traffic.

Another significant determinant for heterogeneous traffic fatalities is street width. Due to the loose lane discipline and lack of vehicle-following, smaller slower vehicles are at high risk for collisions. Because fatalities occur at higher speeds for NMT, midblock locations are the most prominent for highway fatalities in developing countries (Fazio et. al., 1999).

In rural situations, there are issues with expressways being built without parallel facilities and safe crossing for slower modes (Tiwari 2000). These highways often are constructed close to or through the centers of existing villages, forcing residents in lower speed vehicles to cross high-speed highways for access.

Tiwari (2000) also describes the manner of using transit in developing countries as a high cause of traffic fatalities. Buses are crowded, and when one is involved in a collision, large numbers of people are killed. This is especially the case for those hanging from the footboards of the doorways. Trucks and buses overall are involved in 60% of fatal crashes.

Solutions for Reducing Fatalities

Developing countries have been unsuccessful at reducing the lost lives on their roadways, a product of homogeneous countermeasures being unfit for the developing world's traffic mix (Mohan, 2002). Developed countries, where the majority of research is performed, has focused on cars, buses, and trucks. Locally made vehicles are not used in developed countries, such as cycle rickshaws or autorickshaws, and thus little pressure has been behind designing countermeasures that work to prevent fatalities on the modes.

The most significant countermeasure has been to introduce separate facilities for NMT. This typically consists of barrier separated travel facilities, where slower traffic is protected (Tiwari, 2000; Mohan, 2002). These restricted lanes also have had the benefit of improved flow for larger faster modes. Some cities, like Chennai, have implemented signage that restricts each mode to a certain lane. Safe crossing facilities also must be provided, especially at the mid-block where NMT and pedestrians have high fatality rates. Overpasses and underpasses are beneficial, but must be designed appropriately to ensure usage.

Due to the issue of conflicting points at intersections between NMT and motorized vehicles, Mohan (2002) suggests the use roundabouts. The author reasons that this will also aid in traffic flow as well. Some cities have barrier separation only at intersections for NMT turning movements, again with the goal of reducing conflict points.

There also could be policies put forward that reduce the risk from heavy vehicles. Some cities have already put in place time restrictions for trucks to operate in the city, forcing them to travel at night (Fazio et. al., 1999). This also aids in improving flow during the congested daytime. Mohan (2002) describes the idea of reducing fast speeds through limits on engine power for vehicles. Both of these measures would reduce NMT fatalities.

FUTURE OF HETEROGENEOUS TRAFFIC MIXES

Heterogeneous mixes will demand more attention in the coming century, and traffic engineers must be ready to design facilities for these shifts in the mixture of vehicles on the roads. Mixed traffic is already the standard in developing countries, but increases in private vehicle ownership is occurring. The disparity between high and low income earners continues to widen, however, and thus there will be sustained demand for other modes.

Heterogeneous mixes also are becoming more prevalent in motorized developed nations because of the increased attention given to "greener" modes. Transit is gaining in popularity as an alternative to the private car, and people slowly are making the transition to bicycles and walking to reduce the strain of gas prices on their wallets. Freight traffic is increasing as well, and the highways of developed and developing nations will see increased truck volumes.

It is argued by Tiwari (2000) that heterogeneous traffic mixes that operate without lane discipline are the natural optimization of road use, and in some regards may be doing better than controlled homogeneous conditions. There are downsides, especially in the area of safety, and for this reason, there needs to be some degree of control and separation for the modes of different sizes and speeds. Specific countermeasures for mixed traffic must be designed to prevent fatalities, while still allowing for the maximizing of space to occur. Fortunately, some of the best countermeasures also improve capacity as well.

Homogeneous design practices fail the heterogeneous situation. Their traffic flow characteristics are unique, and models must be developed to account for these differences. The drastic need for these in congested developing megacities, coupled with the growing frequency of them in the developed world, will be the call for increased research efforts in this realm.

REFERENCES

1. Arasan, V. T. and K. Krishnamurthy (2008). "Effect of Traffic Volume on PCU of Vehicles Under Heterogeneous Traffic Conditions." Road & Transport Research. 17(1): 32-49.
2. Barter, P. A. (2000). "Urban Transport in Asia: Problems and Prospects For High-Density Cities." Asia-Pacific Development Monitor. 2(1): 33-66.
3. Brar, H. S. and Chopra, T. (2008). "Status of Non-Motorized Vehicles in Urban Areas." Institute of Town Planners India Journal. 5(1): 39-43.
4. Dey, P.P., Chandra, S., and Gangoapahyay, S. (2008). "Simulation of Mixed Traffic Flow on Two-Lane Roads." Journal of Transportation Engineering. 134(9): 361.
5. Fazio, J., Hoque, M., and Tiwari, G. (1999). "Fatalities of Heterogeneous Street Traffic." Transportation Research Record: Journal of the Transportation Research Board. National Academy Press, Washington D.C. 1695: 55-60.
6. Gowri, A. and R. Sivanandan (2008). "Evaluation of Left Turn Channelization at a Signalized Intersection Under Heterogeneous Traffic Conditions." Transport. 23(3): 221-229.
7. Khan, S. and P. Maini (1999). "Modeling Heterogeneous Traffic Flow." Transportation Research Record: Journal of the Transportation Research Board. National Academy Press, Washington D.C. 1678: 234-241.
8. Mallikarjuna, C. and Ramachandra Rao K. (2006a). "Area Occupancy Characteristics of Heterogeneous Traffic." Transportmetrica. 2(3): 223-236.
9. Mallikarjuna, C. and Ramachandra Rao K. (2006b). "Modeling of Passenger Car Equivalency under Heterogeneous Traffic Conditions." Research into Practice: 22nd ARRB Conference, Australian Road Research Board**:** 13p.
10. Mohan, D. (2002). "Road Safety In Less-Motorized Environments: Future Concerns." International Journal of Epidemiology. 31: 527-532.
11. Tiwari, G. (2000). Traffic Flow and Safety: Need for New Models for Heterogeneous Traffic. Injury Prevention and Control. Ed.: D. Mohan and G. Tiwari. London, Taylor and Francis.**:** 71–88.
12. Wei, H., Lu, F., Hou, G., and Mogharabi, A. (2003). "Non-Motorized Disturbances and Control Measures at Signalized Intersections in China." Transportation Research Board 82nd Annual Meeting. Washington, D.C., Transportation Research Board**:** 12p.