Traffic Safety and Sustainable Transport Systems in Developing Countries

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***Abstract*—Road safety problems and the efficiency of transport systems are influenced by factors outside the context of the infrastructure itself. This acknowledgement is of great importance when transferring transport systems and road safety policies developed in high-income countries to low-income countries. Policies and countermeasures that have proven to be effective in the mitigation of road safety problems in developed countries may not fit well with the safety needs in settings where road traffic is commonly characterized by a higher degree of heterogeneity. Such characteristic makes underlying concepts of traffic flows theory applied in high-income countries questionable when applied to low-income countries given that they are designed for homogeneous traffic flows. Because they do not account for such varying dynamic and static characteristics of transport modes they fail in delivering adequate results when applied to road environments characterized by heterogeneous traffic. Other important issues are the differences in the mobility habits of the population, the role and the quality of the public transport systems and its characteristics. The objective of this paper is to provide a better understanding on how all these factors correlate and influence the performance and safety of the transport systems and their importance in the development of infrastructures and transport policies that better fit the mobility patterns and safety needs of developing societies.**

***Index Terms*—road safety, high-income, low-income, heterogeneous traffic, transport policies and countermeasures**

I. Introduction

According to the World Health Organization (WHO), 91% of the fatalities due to road traffic accidents occur in low-income and medium-income-countries, and yet, only 48% of the world's vehicles are registered in these countries [1]. The Global Status Report on Road Safety, published by WHO, predicts that by 2030 road traffic injuries will be the fifth leading cause of death worldwide, meaning that road traffic injuries will be one of the major public health problems of future generations, with the highest burden on low-income countries. This trend makes urgent a better understanding of the relationship between national income and traffic and transport systems in different societies. What factors play decisive roles on the mobility patterns and traffic safety in low-income countries? And how can policies and countermeasures successfully applied in highly motorized environments contribute to the efficiency of transport systems in less motorized environments? These are some of the questions raised in current debates on how the dynamics of different societies influence their mobility and traffic safety patterns. Developing Societies are complex systems, with many different rules, different ideas, different customs and different problems than the ones found in developed nations. Our understanding of the lives of its members and the relationship of its individuals with the dynamics of groups is fundamental to planning in such complex systems. Whether in the movement of people or goods, implicit rules of interaction amongst individuals play an important role. However, when we try to plan urban functions in such societies, these subtle rules may often go unnoticed, but to what extent do they affect the dynamics of social functions like mobility?

II. Complex Transport Systems

Road congestion is a pervasive phenomenon that exists in cities all around the world. In a brief way, it is possible to discriminate and characterize these cities as follows:

- The typical European cities, with a dense urban core and fairly good public transport systems but limited road capacity.
- The American cities, with dispersed urban form (urban sprawl), very poor public transport system and a mobility pattern characterized by a higher dependency on the private vehicle.
- The emerging world cities, i.e. cities in developing nations experiencing fast economic growth originating gaps and bigger disparities in society. The urban environment is commonly characterized by rather dispersed but also very dense urban cores whereas the road environment is characterized by a mixed variety of transport modes.

The last of the previously described types of cities constitute the biggest challenge in planning because they

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aggregate several characteristics that can be found in other cities around the world and many others that can't, making more difficult the distinction of patterns in social functions. This makes them very complex social systems, and planning strategies and policies to address problems in such complex environments have also a more complex character. Despite this acknowledgment, it is the opinion of some experts and researchers that these transport systems work fairly well given their complexity, since the movement of people and goods in some cases wok better than in some controlled conditions [2]. This acknowledgment is based on the theory that complex systems have the ability of self-organizing to some extent [3] and therefore some planners argue that solutions for these systems should be based not in planning for details but in creating incentives for a change of behaviors. This framework has been proven effective in some developed world cities to combat problems like road congestion, for example, Jonas Eliasson, Director of the Centre for Transport Studies at Sweden's Royal Institute of Technology (KTH) is dedicated to researching transport flows, analysing how people think about their commutes and what can influence their travel decisions. He helped design, plan and evaluate Stockholm's congestion tax, which was piloted in 2006 and made permanent in 2007 [4]. He applied this theory in the development of Stockholm's road congestion scheme by gradually introducing a symbolic charge in the Stockholm's ring road to assess the behavior of drivers. Although this scheme benefitted of experiencing periods, normally not feasible in traffic safety, it is generally agreed that the key problems of planning complex systems are in fact the difficulties with their formal modeling and simulation, and consequently, the need to perform experiments. Since road safety phenomena cannot be reproduced in the controlled conditions of a laboratory, which isolates unwanted externalities [5], to be effective, transport and traffic safety policies in developing countries must be based on local evidence and research and designed for the particular social, political and economic circumstances found locally in these countries.

The existing road traffic fatality data and trends by national income and modal share published by WHO shows that in less motorized countries the so-called vulnerable road users (pedestrians, bicyclists, motorcyclists, etc.) make the gross majority of crash related deaths whereas in motorized countries these categories of road users make up for a much smaller proportion [1]. These figures reflect the degree to which road users in different societies are exposed to road traffic and to its consequences, i.e. their risk exposure. Risk exposure is a determinant factor influencing road safety. Everyone who participates in traffic on a daily basis is exposed to a risk of injury or fatality due to a traffic accident and therefore, mobility patterns also play an important role in these numbers, i.e. "…the longer or more frequently people travel, the more road accidents may occur" [6].

When comparing the period when most of today's high-income countries were rapidly motorizing with today's fast motorization of low-income countries, the higher mixture of traffic modes in today's trend stands out as the most important factor. For example, when high-income countries rapidly motorized there was a substantial decrease in walking, and consequently, a reduction of the risk exposure associated to pedestrians.

In developing nations the choice of transport mode is highly influenced by socio-economic variables. Despite the rapid economic growth that some of these nations are experiencing, it is not expectable the same reduction on vulnerable road users to occur, because rapid economic growth leads to extremes of wealth and poverty which in turn gives rise to dual economies. This means that a significant share of the population will continue to favor the most affordable means of transport, i.e. the pedestrian mode and also a varied number of other human powered vehicles and locally designed vehicles (public transport, when existent, is still not affordable to large part of the population), whereas other share of the population will contribute to the increase in the number of fast-moving motorized vehicles. This higher mixture of transport modes increases the disparity of speeds on the road environment, with fast-moving and safer motorized vehicles sharing the same road space with slow-moving vehicles that do not follow any kind of safety standards. This situation increases substantially the complexity of traffic streams, the interactions between modes and consequently, the risk exposure of the most vulnerable users, i.e. pedestrians, two-wheelers and non-motorized vehicles. Furthermore, the road infrastructure poses and additional problem, since they are conceived on the basis of homogeneous traffic models and designed for higher speed vehicles. Also, they commonly cross high-density urban areas endangering all traffic participants.

It is interesting to note that in many developed cities, the segregation of modes is starting to be pointed as an adding factor to the problem of unsafe road environments, whereas in developing countries, segregation might be part of the solution. In developed world cities, segregation of modes is being held responsible in many situations for giving rise to conflicting road user behaviors and to a miss-perceived sense of safety. Consequently, the concept of *shared space* has gained notoriety in many European cities. The concept is based on behavioral and psychological theories and it considers that drivers in a shared space (sucintly, a shared space is road environment where no road signs or mode segregation mechaninsms exist to regulate traffic. The road environment is designd to be shared by all road users and to be self regulated) become integral part of the social and cultural context. As a result, behavior is controlled by everyday norms, not by regulations, and consequently drivers slow down, drive more carefully and start to rely on eye contact and human interaction. In fact, this approach turns regulated road environments into functional complex systems, where behaviors are not enforced by rules but induced by the surrounding environment. John Adams, professor of

geography at University College London argues that the change of behaviors in traffic is related to how humans shift the balance of risk according to their perception of safety (risk compensation effect) [7]. Due to this redistribution of the burden of risk, drivers and pedestrians naturally become more attentive, and vulnerable road users benefit of more control.

In developing countries, where intercity roads pass through the center of towns, and traffic rates are extremely high, road space shared by high mixes of transport modes increases substantially the conflicting situations in the traffic streams. Although risk perception has a somewhat regulating effect in these situations, extremely high risk exposure found in these road environments often leads to higher number injury and fatalities.

These two different perspectives of the concept of shared space show how inversed approaches can fit the realm of different societies depending on the complexity of its traffic system. Hence, complexity is part of the problem in developing societies but can be part of the solution in developed countries. In developing societies, evidence points in the direction of more intelligent mode separation, which leads to a reduction of the complexity of the traffic system.

III. Traffic Flows in Developing Countries

The previous section made clear the need for careful analysis of policies and measures developed in high-income countries when addressing road safety problems in low-income countries. There are many different variables to account in developing nations that were not present when the development of these policies and consequently, they can't be implemented without further adaptations and improvements to suit the characteristics of the road environment and mobility patterns in developing societies. As previously stated, they need to be re-designed for particular social, political and economic circumstances found in developing nations. We are now faced with a situation where more than half of world's population is living in cities in developing regions [8]. Large differences in wealth and social disparities has led to the development of different social layers within a same region, each layer with its own land-use patterns exist in close geographical proximity with other cities with different patterns. This is reflected in the travel and traffic patterns of these regions which is the reason why road safety and transportation policies cannot be global in nature, but object to adaptations and improvements based upon local evidence and research on the following topics:

a) Urban density and mix of land use
b) Low-income and high-income population
c) Modal split
d) Travel and traffic patterns
e) Existing transport modes categories
f) Existing vehicle safety standards
g) Road accident patterns
h) Road user behaviour
i) Education and information
j) Existing legislation and enforcement
k) Road Infrastructure
l) Existing public transport systems

The road network in developing countries is used by several different categories of motorized and non-motorized vehicles, which can vary in length, width and speeds. These differences influence the behavior of road users in the traffic streams, as vehicles move by sharing lateral as well linear gaps and hence road users have differing critic distance and gap acceptance patterns than the ones observed in homogeneous flows. The car following theory used in homogeneous traffic flow models is mostly based in lane discipline, the interaction between vehicles and headway distributions, which in turn vary according to traffic flow rates [9]. The problem when transferring these models to heterogeneous traffic flows is that all car-following and lane changing logic differ substantially from the homogeneous flows (Fig. 1 and Fig. 2).

In developing countries one can find at least seven categories of motorized and non-motorized vehicles in the traffic streams, with widths ranging from 1m (bicyclist operating space) [10] to approximately 3.0 m (typical bus dimensions) and capable of maximum speeds ranging from 15 to 100 km/h.

The combination of these diverse vehicle dimensions and characteristics with the lack of any effective channelization, mode segregation or control of speeds leads to situations of total gridlock in traffic. The car following notion used in homogeneous traffic flow models do not apply in these situations since they do not comprise most of the traffic mixture. If we think of the notion of queue (in the context of road traffic), the immediate image that comes forward is the one found in homogeneous traffic flows, one-dimensional queues. This queue may be a moving queue or a stopped queue but is essentially an excess of vehicles stored upstream of a bottleneck [9]. Whereas In homogeneous flows, entities in the traffic stream form one-dimensional queues, in heterogeneous flows queues form lengthwise as well as laterally due to the disparities in gap acceptances of the different transport modes participating in traffic. Hence the Importance of a better understanding on how the transport mode distribution changes in the road environments with income levels and the need for future traffic models to account for different transport modes having conflicting requirements in the traffic stream.

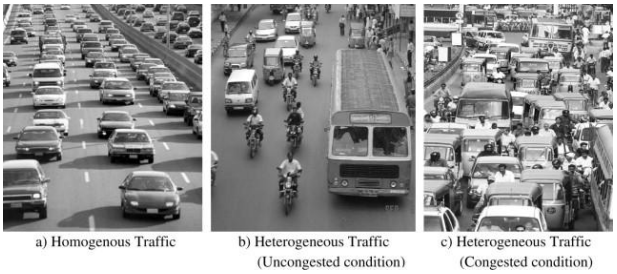

Figure 1. Homogeneous and heterogeneous traffic streams [11]

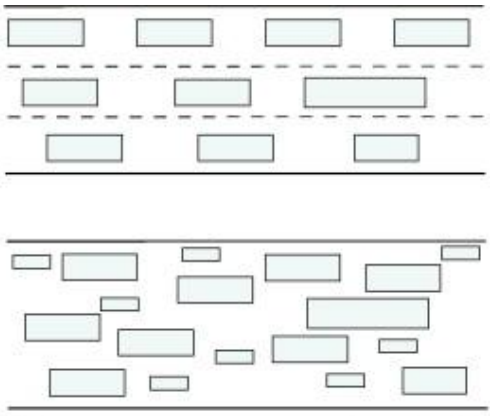

Figure 2. Schematic representation of homogeneous and heterogeneous traffic flows [12]

Another problem faced by developing countries experiencing fast motorization is the safety standards of the vehicles participating in traffic.

Vehicles are exported from motorized countries to less motorized countries that do not meet safety standards in their country of origin and are sold in developing countries for a much lower price. This is a growing business that is boosting car ownership in developing countries at the expense of the safety of its population. Adding to this problem is the locally manufactured vehicles that also lack any kind of safety conditions.

Given the escalating dimension of road accident rates in many developing countries, efforts should be made in order to create mechanisms that prevent that less safer vehicles, coming from developed nations, reach the road environment of developing nations. Emphasis should be given to the enforcement and compliance to minimum International standards and applied to all vehicles, including those locally manufactured.

IV. Brief Overview Of Existing Research On Transferring High Income Countries Road safety Policies to Low Income Countries

It is recommended by WHO that successful policies from developed countries should be imported and adapted to developing nations [1]. At the same time, it is agreed that this recommendation should be addressed with caution, and that success cases of developed nations cannot be simply transferred without further adaptations and innovative research. The rapid motorization of developing countries has given these issues an emergent character and the acknowledgement that they have been almost totally neglected in the past gives scope for innovative and applied research in this area. One good example of new approaches to these problems can be found in the model developed by Mark King [13], researcher in the Centre for Accident Research and Road Safety of the Queensland University of Technology (Brisbane, Australia). King developed a model based on an ecological approach to the transfer of road safety measures from developed societies to less motorized ones. He first accessed on the existing best practice sources and research on road safety transfer, and came to the conclusion that, despite the lack of literature in this area, "a common element across these sources was the recognition that the context is important" [13] and found that factors that influence the success of road safety transfer lie within the following categories: Economic, Institutional, social and cultural.

He then defined the theoretical concept of *road safety space* as a space defined by the economic, institutional, social and cultural factors and that vary with road safety problems and from country to country.

The model considers a particular road space in a particular country as a kind of ecosystem and the transfer of a road safety measure from another country analogous to introducing an outside species into a host ecosystem, this transfer would have the effect of changing some existent features in the host environment.

King argues that, this approach requires an understanding of how a country's road safety space functions and more importantly, how the measures function in its originating country, and how its introduction in the host country will interact with pre-existing road safety systems and phenomena.

Based upon this biological metaphor he presents the following process for applying this model to road safety transfer [13]:

1. Use the model to identify the contextual factors which influence the issue of interest.
2. Nominate candidate countermeasures which have been shown to be effective in developed countries.
3. Use the model to identify the contextual factors which influenced the success of these countermeasures.
4. Determine whether – given the context in the recipient country – these countermeasures are likely to be successful as they stand, or only after adaptation to local conditions, or only if the local context can also be changed, or not at all.

Although he considers that the *road safety space* model is in nature mainly exploratory research, he made an attempt to test its practicality in terms of feasibility and usefulness by undertaking two case studies in Asian Countries.

The conclusions drawn from these case studies were the following [13]:

- With respect to the feasibility of the approach, it became clear that a lot of background information on the recipient country would be needed, until a sufficient information base had been developed.
- With respect to the utility of the model, the information available indicated that the use of the road safety space model would have been of benefit.
- The effectiveness of the model would be enhanced by the systematic development of information on road user behaviour in different countries as well, as this appears to be a significant gap in knowledge.

King concludes that the findings of this research are relevant to road safety transfer in other less motorized regions of the world, and may also be relevant for areas

other than road safety, in particular public health and traffic engineering.

Another example of research on developing nation's road environment can be found in the paper of Nair, Mahmassani and Miller-Hooks [12]. They propose a model that describes disordered heterogeneous traffic streams and how vehicles use gaps in these traffic streams, called porous, to move ahead through lateral gaps. This model captures the influence of speed (closely related to automotive power) and how smaller vehicles exploit their maneuverability to use these gaps (porous) and fast moving vehicles press their advantage of greater engine power. The model presents a speed-density relationship that explicitly considers de pore space distribution and captures the considerable dynamics between vehicle classes.

V. Conclusions

It is interesting to note the shift in the mobility habits in many high-income countries in recent years, induced by the global financial crisis and/or global environmental awareness. Many of these countries have been experiencing an increase in the use of soft modes of transport such as bicycling and walking, which re-opened the discussion on how to plan for better transport infrastructures given the increased risk exposure of these road users. If one thinks in a global perspective, the road environment of low-income countries can provide useful data and better insight on traffic patterns encompassing higher risk exposure of vulnerable users such as bicyclists and pedestrians, and contribute to solutions for high-income nations. If policies and countermeasure cannot in fact be global in nature, there is clearly space for a knowledge transfer between developing world societies and developed ones. This acknowledgment reinforces the need to invest more efforts in innovative solutions and research to address developing world cities problems since they can have much broader scope of applicability than the ones perceived at first sight. There are several areas in the domain of transportation, urban planning and traffic safety that caress of further knowledge about how they function and evolve in a developing city environment. This is clearly an under researched and sub-explored area by planners and researchers.

This paper covered some of these subjects, either in the domain of transport or traffic safety, they need to be urgently addressed in developing nations. Evidence exist that there is much space for improvements in the following areas:

- Intelligent segregation of modes in the road environments;
- Traffic calming measures adapted to different types of vehicles other than the car;
- Risk exposure control;
- Friendly vulnerable road user infrastructure designs and
- Vehicle safety standards regulations

Improvements in any of these areas are likely to play an important role in the reduction of traffic injuries and fatalities in developing world cities. Also, the development of new frameworks to the orchestration of policies to address these problems is crucial to the sustainable economic growth and social welfare in these nations. These should be based on new models and theories designed for complex social systems and on the careful adaptation of proven successful methods from developed countries.

The complexity of transport systems in developing nations embark several aspects not found in developed ones and therefore, future directions should be defined for developing societies. What can be inferred from this paper is the need for more research and demonstration projects to be funded, since designs and policies for many interventions which are likely to succeed, are not currently entirely clear and available.

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