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Publications

RESEARCH PAPERS

Methodology for estimation of probable location of VRU before impact using data from post-crash analysis. Subramanian, Hariharan S., Sudipto Mukherjee, Anoop Chawla, and Dietmar Göhlich (2014). *In IRCOBI Conference Proceedings; IRC-14-48, pp., 414-427.*

Optimization study on multi-body vehicle-front model for pedestrian safety. Sankara Subramanian H, Chawla A, Mukherjee S, Goehlich D. (2014). *The 16th International conference on Machine Design and Production (UMTIK 2014). Izmir, Turkey.*

Combined empty and loaded train scheduling for dedicated freight railway corridors. Upadhyay, Amit, and Nomesh Bolia (2014). *Computers & Industrial Engineering 76, pp. 23-3.*

Impact of road traffic crashes in Asia: a human and economic assessment. Mohan, Dinesh (2014). *Eighth Regional EST Forum in Asia, United Nations Centre for Regional Development, Tokyo; pp., 1-13.*

Re-fueling road transport for better air quality in India. Guttikunda, Sarath K., and Dinesh Mohan (2014). *Energy Policy 68, pp., 556-561.*

Assessment of motor vehicle use characteristics in three Indian cities. Mohan, D., Goel, R., Guttikunda, S., & Tiwari, G. (2014). *Lyngby, Denmark: UNEP Risø Centre on Energy; pp., 54.*

Particulate and gaseous emissions in two coastal cities—Chennai and Vishakhapatnam, India. Guttikunda, S. K., Goel, R., Mohan, D., Tiwari, G., & Gadepalli, R. (2014). *Air Quality, Atmosphere & Health, 1-14. DOI 10.1007/s11869-014-0303-6.*

Review of cellular automata model for heterogeneous traffic conditions. In Traffic and Granular Flow; Pandey, G., Rao, K. and Mohan D. (2014). *Springer International Publishing Switzerland. DOI 10.1007/978-3-319-10629-8_52; 13* (Eds. M. Chraibi et al.).

Energy for transport. Figueroa, Maria, Oliver Lah, Lewis M. Fulton, Alan McKinnon, and Geetam Tiwari (2014). *Annual Review of Environment and Resources, 39; pp., 295-325.*

Impacts of bus-stops on the speed of motorized vehicles under heterogeneous traffic conditions: a case-study of Delhi, India. Bansal, Prateek, Rishabh Agrawal, and Geetam Tiwari (2014). *International Journal of Transportation Science and Technology 3, no. 2; pp., 167-178.*

Impact of cycle rickshaw trolley (CRT) as non-motorised freight transport in Delhi. Sadhu, SLN Sarma, Geetam Tiwari, and Himani Jain (2014). *Transport Policy 35; pp., 64-70.*

Planning and designing transport systems to ensure safe travel for women. Tiwari, Geetam (2014). *International Transport Forum Discussion Papers, no. 2014-04.*

Benchmarking vehicle and passenger travel characteristics in Delhi for on-road emissions analysis. Goel, Rahul, Sarath K. Guttikunda, Dinesh Mohan, and Geetam Tiwari (2014). *Travel Behaviour and Society 2 (2); pp., 88-101.*

The role of cycle rickshaws in urban transport: today and tomorrow. Tiwari, Geetam (2014). *Transfers 4.1; pp. 83-96.*

Particulate and gaseous emissions in two coastal cities—Chennai and Vishakhapatnam, India; Guttikunda, Sarath K., Rahul Goel, Dinesh Mohan, Geetam Tiwari, and Ravi Gadepalli (2014). *Air Quality, Atmosphere & Health; pp., 1-14; DOI 10.1007/s11869-014-0303-6.*

Driver behaviour and warning signs in highway work zones. Gupta, Sumeet, Yogender Singh and Geetam Tiwari (2014). *In Transportation Research Board 93rd Annual Meeting, no. 14-5728.*

Moving beyond safety legislation: research agenda for 2015. Tiwari, Geetam (2014). *International journal of injury control and safety promotion, 21, no. 4; pp., 303-304.*

The decade of action for road safety–progress in research. Tiwari, Geetam (2014). *International journal of injury control and safety promotion, 21, no. 2; pp., 101-102.*

Static analysis and strength reliability of human femur bone. Yakkala, Viswanath, Suhail Ahmad, Puneet Mahajan, and Pankaj Prajapati (2014). *In American Society of Mechanical Engineering (ASME) 2014 12th Biennial Conference on Engineering Systems Design and Analysis, pp. V001T03A008-V001T03A008.*

Multiple classification analysis for trip production models using household data: case study of Patna, India. S.B. Ravi Gadepalli, M. Jahed, K. Ramachandra Rao¸ G. Tiwari (2014). *Journal of Urban Planning and Development, ASCE, 140-1.*

Determination of sample size for speed measurement on urban arterials Varsha, V., Pandey, G.H., K. Ramachandra Rao, Bindhu, B.K. (2014). *TPMDC-2014 International conference, IIT Bombay, Transportation Research Procedia.*

RESEARCH REPORTS

Assessment of motor vehicle use characteristics in three Indian cities. Dinesh Mohan, Rahul Goel, Sarath Guttikunda and Geetam Tiwari. *UNEP Risø Centre on Energy, Climate and Sustainable Development Technical University of Denmark, 2014. http://www.unep.org/transport/lowcarbon/PDFs/AssementMotorVehicle.pdf*

Case study of metro rails in Indian cities. Rahul Goel and Geetam Tiwari. *UNEP Risø Centre on Energy, Climate and Sustainable Development Technical University of Denmark, 2014. http://www.unep.org/transport/lowcarbon/PDFs/CaseStudy_MetroRails.pdf*

Work zone safety manual. K.N. Jha, D.Mohan, G.Tiwari, A.K.Roy, K.R. Rao and S.Mukherjee. *National Highway Authority of India, June 2014.*

Traffic safety in Agra. D.Mohan, G.Tiwari and S. Mukherjee. *IATSS, Japan, June 2014.*

Planning and design guideline for cycle infrastructure. Geetam Tiwari. *Shakti Sustainable Energy Foundation, 2014.*

The **Transportation Research and Injury Prevention Programme (TRIPP)** at the Indian Institute of Technology Delhi, is an interdisciplinary programme focussing on the reduction of adverse health effects of road transport. TRIPP attempts to integrate all issues concerned with transportation in order to promote safety, cleaner air, and energy conservation. Faculty members are involved in planning safer urban and inter-city transportation systems, and developing designs for vehicles, safety equipment and infrastructure for the future. Activities include applied research projects, special courses and workshops, and supervision of student projects at postgraduate and undergraduate levels. Projects are done in collaboration with associated departments and centres at IIT Delhi, government departments, industry and international agencies.

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PEDESTRIAN SAFETY VERSUS TRAFFIC FLOW: FINDING THE BALANCE

Experpts from 7th TRIPP Annual Lecture

Robert B Noland

Modern and developing cities are characterized by the pervasiveness of motorized traffic. Western nations began this process over a century ago when motorized vehicles originally became commonplace and ownership and use grew rapidly. Over the last 10-20 years, many rapidly developing nations are facing the same growth in motorized vehicle usage and are facing many of the challenges that the developed world tackled in the past. While there are well known benefits to motorization, there are also costs. Many countries are making the same mistakes that western nations have been trying to fix over the last few decades. The promotion of mobility and traffic flow over other goals is now seen as having damaged the well-being of cities mainly by taking space away from people with consequences on the ability of people to walk and engage in activities without motorized transport. This paper provides an overview of the conflict between pedestrian safety and designing and building streets to maintain efficient traffic flow. I start with an historical perspective on the early conflicts over the use of streets in both Great Britain and the United States. This is followed by a discussion and critique of the guidance developed by traffic engineers to improve traffic flow and more recently traffic safety. The effectiveness of various approaches to improving both traffic and pedestrian safety are then discussed, based on recent research, while noting that in the United States, our safety data still has many problems. Conclusions focus on solutions with a focus on shifting more street space to pedestrians as a way of improving both safety and the livability of cities. The results of a cost/benefit analysis of one specific approach, a road diet, that reduces vehicle capacity is presented and shows overwhelming positive benefits. I close with some discussion of how developing nations can tackle these issues before it is too late.

Starting in the mid-19th century, before motorized vehicles, conflicts began to develop over the use of city streets in Britain. Horse-drawn carriages (also known as omnibuses) became much more common as incomes grew with the industrial revolution. Pedestrians dominated city streets and these new forms of transport were a hazard resulting in both fatal and injury crashes. As early as 1840, there were about 1000 deaths recorded and fatality rates averaged about 50 per million. For comparison, the rate in 2013 was about 26.72 per million (based on 1713 road deaths) (Department for Transport 2013). While data records in the 19th century may not be accurate, this implies that the fatality rate associated with road transport has only been cut in half in 170 years; however, mobility is vastly improved and we will return to this trade-off later.

Those responsible for traffic casualties were liable to have their vehicle forfeited under British law. This was known as the Law of the Deodands, and objects involved in the death of a person were forfeited to the Crown. This law, however, was repealed in 1846, just at the time that deaths from traffic were increasing. The reason for this was that jurors often did not convict the vehicle owner, partly because they owned vehicles themselves and they saw the forfeited items ending up with "lords and churches instead of with the family of the deceased". This shows how those who were more mobile (and normally more privileged people sat on juries), sought to minimize the penalties associated with the benefits of mobility. This persists to this day, in that penalties for vehicle drivers who kill pedestrians are often trivial.

It also suggests that pedestrians were considered to be more blame-worthy for their fate than the drivers of carriages and omnibuses. The right to the mobility of these vehicles was seen as more important than the safety of those who were walking. One jurist wrote in 1869: "Accidents happen because the drivers do not believe, or at any rate will not admit, that foot passengers had as much right to cross a street or thoroughfare as persons driving has to pass along it." This sounds very familiar to debates that we hear today over the use of road space.

As traffic increased, policy and regulations were developed to both protect pedestrians and guarantee the ability for traffic to flow unimpeded. Three approaches in particular were followed in Britain. These were the requirement that footpaths (sidewalks) be built along streets, the development of traffic signals and ways for pedestrians to cross streets, and the building of guardrails along sidewalks to channel pedestrians to designated crossing points.

Sidewalks are undoubtedly useful for protecting pedestrians from fast moving traffic, but also allow that traffic to move in the street by removing the right of pedestrians to walk in the street. A 1906 letter published in the Proceedings of the Institute of Civil Engineers sums up the attitude: "It is unfair to the motor car driver, as well as to the pedestrian, to allow any important road to be without a footpath". Design standards for footpaths in London were quite liberal, requiring that they have a width that is 1/6th of that of the total carriageway. The latter were often 24 ft (7.3m) in width, thus the footpaths were at least 4 ft (1.2m) in width on both sides of the street. Footpaths were also seen as a sanitary measure to improve drainage and to bring more order to city streets, especially in the slums.

The first traffic signal started operation in 1869 in front of the Houses of Parliament in London. This was a gas-fired semaphore, similar to railroad signals. It provided a 30 second window for pedestrians to cross every five minutes. This made compliance by pedestrians unlikely as the wait time was long and most carriage drivers also did not stop, given their unfamiliarity with the new technology. The signal itself suffered from several gas explosions. In any event the experiment was discontinued in 1870 as many Members of Parliament protested. After the failure of this experiment, debate turned to other means for pedestrians to safely cross streets while allowing traffic to flow unimpeded. Police officers often guided pedestrians across streets, but this was seen as costly. Subway tunnels and footbridges were considered. The latter were considered to be unsightly and land acquisition costs would be high. The first pedestrian subway was opened in 1870 (near the failed semaphore). Many of these were built in subsequent years, but debates over the best means for pedestrians to safely cross streets continued.

There was a recognition that many people would still cross at street level even if a subway tunnel or footbridge was present. Well into the 20th century there was little consideration of simply stopping traffic at key pedestrian crossings, suggesting that traffic flow was more important than providing safe pedestrian crossings. Adding to the debate was the concern expressed in this statement before the House of Lords in 1938: "We do feel that if subways and bridges were put into general operation it would only confirm the view of the motorist that the public highway was a motor speed track and would lead to further accidents."

The other engineering measure taken was the installation of guardrails along sidewalks and also within median refuges. These served the purpose of keeping pedestrians from entering the street and also channeled them to designated crossing points. By assuring that pedestrians could no longer enter the street facilitated the free flow of traffic. These were widely built in the 1930's as motorized traffic increased, some as much as 5 kms long on some East London streets. These were very effective at keeping pedestrians out of the street. By the 1930's, the conflict between which mode dominates the street and what the purpose of the street was had clearly been decided in favor of the motorcar at the expense of the pedestrian.

A similar story was playing out in the United States, as documented by Peter Norton in his seminal book, Fighting Traffic, The Dawn of the Motor Age in the American City. In the 1920's the main victim of increased motorization was children. The vast majority of traffic fatalities in cities was pedestrians (for example, in Philadelphia, pedestrians accounted for 75% of total traffic fatalities) and about half of these were children. Children and their parents were used to the streets being places where children could play and wander freely. But with the danger introduced by motorized vehicles there was outrage at the carnage that was occurring. In some cities monuments to children slain by vehicles were erected. As parents protested the conditions, the motor vehicle industry fought back and defended the "rights" of the population to be mobile. Some cities considered implementing speed restrictions. In 1923, Cincinnati, Ohio, debated an initiative that would have required speed governors in all vehicles.

In response, the motor industry developed a strategy of shifting blame to pedestrians and children, implying that parents were irresponsible to let their children play in the streets. They created the term "jay-walker" to mock pedestrians who did not cross at designated crossing points; in fact, one year after the Cincinnati initiative failed, Los Angeles passed the first law against jay-walking. As in Great Britain, by the

1930's the battle over the use of street space had been decided with the motorcar firmly in control (Norton 2008).

In the 1920's, as motor vehicle traffic rapidly grew, cities were confronted with the problem of vehicles congesting central business districts. In response, and frequently at the behest of the business community, municipal engineers (the forerunner to today's traffic engineers) sought methods to improve the efficiency of traffic flow. As discussed above, one means was controlling pedestrian movements. Many engineers also saw the provision of more electrical transit systems as one way to improve efficiency. But other engineering approaches were also tried, including coordinated traffic signals (in Chicago), eliminating on-street parking, and ultimately reconfiguring the city itself to provide more road capacity for vehicles.

As early as 1925, the first formal engineering guidebook, Street Traffic Control, was produced. After the Second World War, growth in vehicle ownership accelerated. The Highway Research Board (forerunner to the Transportation Research Board) produced the first version of the Highway Capacity Manual in 1950. Updates have been produced every few years (the current being 2010). In 1965, the concept of "Level of Service" was introduced. This was a means of classifying the travel delay associated with highways and intersections. Underlying the concept are detailed calculations of traffic flow, queueing, and signal timings, but the output produces a simple A to F ranking of the level of service (A being the best, and F being the worst). In practice, C provides a reasonably stable flow of vehicles, and most traffic engineers become concerned only at levels of D and lower. For intersection level of service, the rankings are linked to estimated delays for both signalized and unsignalized intersections.

Level of service (LOS) requirements have been extremely influential. In most, if not all, major cities and towns in the US, any new development requires an analysis of LOS. If a new development (or redevelopment) leads to a degradation of LOS, usually below C, then the developer must either scale back the size of the development or fund mitigation measures such that there is no reduction in level of service. These measures may include increases in the width of the road, changes to the turning lanes at intersections, or installation of traffic signals. The incentive for the developer is frequently to simply build in an area with minimal existing traffic on the edge of the urbanized area; in other words, this encourages sprawling development patterns. But mitigation measures in developed areas make the pedestrian environment less friendly, such as increasing the time needed to cross streets, or by encouraging faster traffic speeds from widening the road, or installing turning lanes.

Thus, engineering guidelines as implemented via LOS requirements became the foundation for how cities grew after the mid-1960's. In 2015, some fifty years after their promulgation in the Highway Capacity Manual, there is debate over the value of using this metric as the only performance criteria for both changes in street design and land use. In California, environmental legislation required an LOS analysis for all new developments, leading in most cases to worse environmental outcomes as new development located in areas where there would be no impact on existing traffic. Recently, legislation has been passed in California that allows development in "transit-rich" or infill areas to not be subject to this requirement.

Another important guidance document is "A Policy on Geometric Design of Highways and Streets", aka "the Green Book", produced by the American Association of State Highway and Transportation Officials. This guidance document sets standards for how highways should be built, such as the width of traffic lanes, the curvature, and a large variety of other detailed design components. This has resulted in the design and construction of highways and streets that are "wider, straighter, and faster", primarily because these are seen as being both efficient and safe highways. As Dumbaugh, Gattis (2005) show, the concepts of rural road arterial design have been applied to urban streets, while forgetting that in urban areas pedestrians are present, and the function of the road is very different that than in a rural area. The Green Book has little consideration of the role of pedestrian movements, although the most recent guidance does recognize that pedestrians provide vitality to central business districts and thus should be catered to. Much of the limited discussion on safety issues in the Green Book is dedicated to creating "clear zones", that is, a buffer whereby vehicles running off the road do not hit obstacles (e.g. trees). While the guidance recognizes this may be difficult to do in urban areas, it still recommends doing as much as possible to remove roadside objects, precisely those that may protect pedestrians walking on sidewalks.

Developed countries have seen enormous drops in fatalities associated with traffic crashes over the last 40 years. This has occurred despite increases in vehicle usage and total populations. Recent research I have conducted has sought to identify some of the major policies associated with these trends. Of key interest is the role that road network plays, especially given the large investment in trying to make roads safer. Work that I conducted about 15 years ago sought to examine changes in the road network while controlling for other policies enacted by states. Using a cross-sectional time-series methodology of state-level data it was found that most of the reduction (from 1984-1997) was associated with increased safety-belt use, reduced alcohol consumption, and better medical technology. Changes in demographics also played a role, as the fraction of the population below the age of 25 decreased, which is typically a group at higher risk of crashes. Various road network features were found to have positive associations with fatalities and injuries, such as increases in arterial and collector roads, and overall lane-mileage. While effects were weak, there was evidence that larger lane widths (of arterials and collectors) are associated with more fatalities and injuries.

An updated analysis evaluates a broader set of policies, including those initiated in the last 15 years. These include the implementation of graduated licensing policies, more motorcycle helmet laws, new laws that regulate mobile phone usage, reductions in alcohol consumption, and improved medical technology (as measured by a proxy variable). The economic climate has also had an impact, with the recent recession associated with drops in total fatalities, something seen in many other studies. An increase in the number of lanes for arterials and collectors was associated with more fatalities.

Those policies that tend to increase the cost of mobility, i.e., regulations on driver behavior such as motorcycle helmet requirements, mobile phone laws, and graduated licensing laws, all are effective. Those that reduce the cost of mobility, such as adding more lanes to arterials and collectors, tend to increase fatalities. Improvements in medical technology tend to reduce the likelihood of a fatality, while this reduces the cost of mobility there is still a beneficial impact. This is consistent with what we would expect from behavioral adaptations.

The record on pedestrian fatalities has also shown an improvement, with a fairly steady drop since about 1973. Data prior to this time period was not collected by NHTSA and there is a large discontinuity between 1972 and 1973, but there was likely a large reduction after the reported peak in the early 1930's.

While the national total of pedestrian fatalities has decreased, this is not the case in all states. New Jersey has had a fairly constant number of pedestrian fatalities since 1994. New Jersey has a relatively low incidence of traffic fatalities, but the proportion of those that are pedestrians is one of the highest in the nation (about 20%). This is largely because the state is densely populated, so exposure levels are higher. One can see the relative distribution of pedestrian casualties throughout the state; these roughly track the major population centers in the north and south of the state.

Analysis we conducted has examined both the probability of pedestrian casualties occurring throughout the state and a more detailed analysis of associations between road and pedestrian infrastructure and the level of severity of pedestrian crashes. The crash frequency analysis used spatial data from 2003-2008 to examine factors associated with pedestrian casualties. In general, results show that lower income areas tend to have more casualties and areas with lower household vehicle ownership likewise have more casualties. These would be areas where people are more dependent on walking to engage in economic activities so exposure levels are likely higher. Alternatively, casualty rates are higher in areas with lower population density where streets usually have higher speed limits and fewer safe areas for pedestrians to walk. A greater density of major highways, excluding controlled access highways, is also associated with more pedestrian casualties.

To examine the relative severity of pedestrian casualties, we analyzed the road and pedestrian infrastructure for over 2500 crashes using imagery from Google Street View. The features examined included, the number of lanes, speed limits, presence of sidewalks and whether they had buffers along the street, crosswalk types and presence of medians. The Results suggest that casualties are less severe when there are reduced speed limits, fewer lanes of traffic, and sidewalks with buffers.

In general, these results suggest that a major source of pedestrian fatalities is large high-speed roads without adequate pedestrian infrastructure. These may also be more likely to cut through lower income neighborhoods, partially explaining the frequency of crashes in those areas. In short, roads are not safe for pedestrians. All the images were the site of a pedestrian crash. The former were fatalities while the latter was a minor injury.

Many cities in the United States and throughout the world are now recalibrating the balance of providing unimpeded traffic flow versus providing safety for pedestrians. These concepts range from traffic calming to slow traffic, mainly on residential streets, to shared space concepts, to reallocation of road space to reduce lanes for vehicles and provide more space for pedestrians. Times Square in New York City, which is the heart of the theater district, was bisected by a major arterial road, Broadway. In 2009, Broadway was closed to traffic and the space reallocated to pedestrians. The result has been a substantial increase in pedestrian activity and a much enhanced environment for pedestrians, so much so that space is limited and some are complaining of too many pedestrians. If too many pedestrians are a problem, then one solution is to close additional streets that still traverse the square. In London, a good example of a shared space concept was recently completed in South Kensington along Exhibition Road. This street runs from Hyde Park in the north down to the South Kensington Underground station, passing by a major university and three large museums that attract substantial pedestrian traffic. During peak periods the sidewalks were previously overcrowded and the vehicles on the street tended to speed through the area, making crossing dangerous. The concept of shared space is to send a message to motorists that they will share the road with pedestrians; this is done by eliminating curbs and putting a textured pavement on the street. In this case the speed limit was lowered from 30 mph to 20 mph, which some might argue is still too high.

Another concept being employed in the United States is a Complete Streets policy. This policy aims to reconfigure existing street design so that all road users are accommodated, pedestrians, cyclists, motorists, and transit. One implementation of this is the concept of a "road diet", which involves reducing the number of lanes for streets that were over-designed for vehicle capacity. This commonly involves taking a road with 2-lanes for traffic in each direction and converting it to 1-lane in each direction with a shared turning lane separating the traffic lanes. Normally there is then additional road space to also add a bicycle lane on either side of the street, although not all implementations include this.

We conducted research to evaluate the costs and benefits of implementing a road diet along Livingston Avenue, a 1.5 mile arterial corridor in New Brunswick, New Jersey. This street runs from a major intercity arterial to the center of New Brunswick, traversing mainly a residential neighborhood but with some commercial activity and several schools along its length. The costs associated with the road diet mainly consist of any additional travel time delay associated with reducing the capacity and subsequent vehicle throughput, as well as the construction costs (mostly restriping the pavement) associated with the conversion. The benefits are the expected reductions in vehicle crashes. There are also potential benefits of improving pedestrian mobility, although we did not attempt to assess these.

To estimate the travel delay, we ran several simulations using VISSIM micro-simulation software. The value of travel time applied to the delay was based on formal guidance provided by the US DOT, equivalent to 50% of the median income of $12.75 per hour; for business travel it is 100% of the median income or $25.50 per hour. Values were indexed to 2014. To estimate the cost of crashes, estimates of the value of statistical life were used, again based on US DOT guidance. The 2014 value ranges from $5,311,875 to $13,177,537, with a mean of $9,295,782. As most crashes do not involve a fatality, factors are applied based on the level of severity of a crash. The number of crashes per year is about 38, on average with 17% involving pedestrians and 43% involving an injury. As we do not know precisely what the reduction in crashes will be, we assumed a 19% reduction based on a review of the crash reduction potential of similar road diet conversions. Given the uncertainties about some of our assumptions, we conducted a detailed scenario analysis over a 20 year time frame. In all cases, the net present value of the road diet conversion was overwhelmingly positive. Benefits ranged from about $8 million to over $40 million.

Most of the political debate surrounding road diets involves a fear of creating congestion, or reducing the level of service of the street. This was the case in New Brunswick as there was a desire to complete the study well before an upcoming election. However, shortly after the study was completed, three children were hit by a vehicle and one suffered serious injuries. After political protests over the safety of the street, the City began more detailed engineering work and committed to doing the conversion. Some initial restriping was done in front of schools along a few blocks of the street, shortly after the crash. It is not known when the final project will be completed.

In this paper, I have reviewed the historical conflicts over road space and their resolution in favor of the motorcar in both Great Britain and the United States. While these conflicts were suppressed for many years, they have recently reemerged, recognizing that engineering guidelines on how to build roads ignored the pedestrian and damaged the fabric of many cities. The viewpoint that insists on reducing traffic congestion and facilitating traffic flow at any cost has been challenged.

From a research perspective it is important to continue to evaluate the relative costs and benefits of traffic flow versus pedestrian safety. Benefits of pedestrianization can be more difficult to measure than travel time savings for vehicles. While safety improvements are one measure, other quality of life improvements are difficult to quantify. Safety data systems also need to be up to the task, they clearly are not in the United States and developing countries often have even less reliable data systems. Making this data publically available, both for researchers and to enforce government accountability is crucial. What are the lessons for developing countries, especially those that are rapidly motorizing? While motorization can improve mobility and economic linkages, it must be managed in such a way that the city is not destroyed as a place where pedestrian activity can thrive. Large high-speed arterial roads are chasms that pedestrians cannot cross and damage the linkages between neighborhoods. Traffic engineers and transport planners need to be thoughtful about following engineering guidance documents on how to design roads and improve safety. The locational context of where road infrastructure is placed must not be ignored. The main lesson is to find the right balance, and many cities have gone too far in catering only to motorized traffic at the expense of pedestrians.

There are growing examples throughout the world of successful reallocation of space from vehicles to pedestrians. These increase the vibrancy of neighborhoods and reduce many of the negative costs associated with an overreliance on motorized transport. A good example in India is Raaghiri Day. This is a weekly event where selected streets are shut down to traffic and opened to all for entertainment and recreation. This is part of the Open Streets movement that seeks to reclaim streets for all users. Originating in Bogota, Columbia, with Cyclovia, these have proliferated throughout the world. These serve to educate the public about how streets can be used for other purposes, and hopefully will lead to broader institutional changes.

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Excerpts from two publications: A TRIPP BULLETIN INSERT

Particulate and gaseous emissions in two coastal cities - Chennai and Vishakhapatnam, India

The presence of land sea breezes is advantageous to Chennai and Vishakhapatnam. With most industrial and power plant emissions dispersed to the sea, their overall impact on the urban air quality is lessened. However, the same is not true for the diffused emissions, such as the vehicle exhaust, domestic cooking, open waste burning, and road dust, which are steadily increasing. In this paper, we present sector-specific emissions inventory for particulate and gaseous pollutants, which is spatially disaggregated at 0.01° resolution, suitable for atmospheric dispersion modeling. For the urban airshed, the ambient particulate concentrations were modeled using the ATMoS dispersion model, which when overlaid on gridded population, resulted in estimated 4,850 and 1,250 premature deaths and 390,000 and 110,000 asthma attacks in year 2012, for the Greater Chennai and the Greater Vishakhapatnam regions, respectively. The total emissions are also projected to 2030. Under the current growth rates and policy assumptions, the pollution levels are likely to further increase, if the expected changes in the industrial energy efficiency, environmental regulations in the power plants, and fuel standards for the vehicles are not introduced as planned.

Epidemiological studies from India show high rates of respiratory and cardiovascular diseases in populations exposed to particulate matter (PM), nitrogen oxides (NOx), and ozone pollution (Chhabra et al. 2001; Pande et al. 2002; Gupta et al. 2007; Siddique et al. 2010; Balakrishnan et al. 2013), and there is a growing body of international evidence on the health impacts of outdoor air pollution (IHME 2013). In 2014, the World Health Organization (WHO) listed 37 Indian cities in the top 100 world cities with the worst air quality (WHO 2014). In 2011, a similar assessment listed 27 cities. In this paper, we present, for two coastal cities in India (Chennai and Vishakhapatnam), an overview of air quality monitoring data, emissions from all the known sectors, pollution dispersion characteristics, and an assessment of health impacts and discuss scenarios for building an urban air quality management program.

We defined the study domains such that they were large enough to cover the main district area, the neighboring satellite cities, and locations with sources that could influence the air quality in the designated urban areas. The geographical location of the cities is presented, along with the main roads, highways, points of interest, brick kiln clusters, industrial estates, power plants, and the main urban district boundary. The Greater Chennai domain covers an area of 44×44 km and the Greater Vishakhapatnam region covers an area of 40×40 km, with both the domains subdivided into grids at 0.01° (approximately 1 km) resolution. The two domains consist of three ports, handling up to one fourth of the total traffic at all the major ports of India (IPA 2013).

Chennai (capital of the state of Tamil Nadu) is one of the four metropolitan cities of India, along with Delhi, Mumbai, and Kolkata. With its proximity to the Bay of Bengal and thus access to markets in East Asia, Chennai is also an important and busy port city. Apart from trade and shipping, the automobile industry, chemical and petrochemical industry, software services, medical care, and manufacturing form the foundation of the economic base for Chennai. Manufacturers like Ford, Hyundai, Mitsubishi, Ashok Leyland, Massey Ferguson, Eicher, and other engineering and manufacturing units have taken advantage of the proximity to the port, aswell as skilled labor in the region, to establish manufacturing centers in Chennai, thus accounting for 30 % of India's auto industry.

The Ennore Port, the first major corporate port, handles coal (most of the supply is for the two thermal power plants with dedicated feeder lines running from the ports), iron ore, oil, and commercial commodities for the automobile and mineral industries. The annual capacity of 30 million tons of cargo in 2012–2013 is expected to triple by 2020, which is linked by road and rail transport, to most parts of South India. There are 8.7 million inhabitants in the Greater Chennai region, covering a city area of 1,200 km2. The percentage of households owning a car is 13 %, the percentage of households owning a motor cycle is 47 %, and the percentage of households using a nongas or nonelectric cook stoves is 17 % (Census-India 2012). With US$219 billion in 2012, Chennai metropolitan area is the fourth largest city by GDP in India.

Visakhapatnam is a coastal city, also on the eastern coast of India. It is the second largest urban agglomeration in the state of Andhra Pradesh, after Hyderabad. The port handles petroleum, oil, iron ore, coal, and other commercial goods, and the port is the second largest in India in terms of the cargo traffic. Close proximity to the port has also lead to industrial settlement in the city, consisting of steel, petroleum refining, and fertilizer industries. While the modeling domain size is the same as Chennai, a large part of the Vishakhapatnam domain is covered by hills and forests, and the built-up area is only 30 % of the modeling domain. Besides the port, other factors contributing to the city's economic growth are its location between Chennai and Kolkata and a developed network of railways which changed this valley into an industrial hub. There are 1.7 million inhabitants in the Greater Vishakhapatnam region, covering a city area of 530 km2. The percentage of households owning a car is 8 %, the percentage of households owning a motor cycle is 36 %, Geography and the study domains of Chennai (Tamil Nadu) and Vishakhapatnam (Andhra Pradesh) Air Qual Atmos Health and the percentage of households using a nongas or nonelectric cook stoves is 21 % (Census-India 2012). With US$26 billion in 2012, Vishakhapatnam is the tenth largest city by GDP in India.

Both the cities are industrialized and operate major ports.With less than half the population of Greater Delhi region, the Greater Chennai region has similar magnitude of total PM2.5 emissions. However, there are large differences in the sectoral contributions. Chennai has more than twice the share of PM2.5 from transport sector (39 %) compared to that in Delhi (17 %).While the growth of private vehicles has occurred at a rapid rate, major contributors to road transport emissions were the freight vehicles, all running on diesel, to and from the ports. In such cases, emissions cannot be wholly attributed to city road transport usage alone, as most of the freight movement is regional or national in nature. This is also the case of Delhi where 75 % of all the freight goods that come to the city are redistributed to other parts of the country (mostly northern India).

Similarly, the total number of registered private vehicles (cars and 2Ws) in Chennai and Visakhapatnam is less than half and less than one tenth of those in Delhi, respectively. As a result, there is a large difference in sectoral distribution of pollutants which are associated with vehicular traffic—CO, VOC, and NOx. In addition, unlike Delhi where some power plants are gas-based (and hence leading to more CO emissions), all the power plants in Chennai and Vishakhapatnam are coal-powered. Given the size of the cities, Visakhapatnam has a disproportionate share of electricity production plants. The greater Delhi region (80×80 km) has an installed capacity of 4,000 MW of power plants, while the greater Visakhapatnam region (40×40 km) has an installed capacity of 3,000 MW. While most power plants in and around Delhi cater to Delhi's demand, power plants in Visakhapatnam cater to regional demand through national grid.

The consolidated results from the emissions and the dispersion modeling provided a greater understanding of the spatial spread and the temporal trends in emissions and particulate pollution in the coastal cities of Chennai and Vishakhapatnam. Given the uncertainties, these results further emphasized the need for such integrated studies to support air quality management and to address policy-relevant questions like which sources to target.

In an effort to continuously improve the quality of the data, the emission inventory and activity datasets will be made available via the internet. The inconsistencies in the procedures, such as emission factors and spatial weights for gridding, will be corrected and supplemented with additional data as they become available in future research in Chennai and Vishakhapatnam. In this study, we presented the results for total PM pollution, a key criteria pollutant and often exceeding the national ambient standards. However, the emissions inventory includes ozone precursor pollutants (NOx, VOCs, and black carbon) and their spatial and temporal disaggregation, suitable for photochemical transport modeling. We intend to extend the dispersion modeling analysis to total chemical transport modeling using models like CAMx to evaluate impacts of ozone on health and environment.

Particulate and gaseous emissions in two coastal cities—Chennai and Vishakhapatnam, India; Guttikunda, Sarath K., Rahul Goel, Dinesh Mohan, Geetam Tiwari, and Ravi Gadepalli (2014). Air Quality, Atmosphere & Health; pp., 1-14; DOI 10.1007/s11869-014-0303-6.

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Optimization study on multi-body vehicle-front model for pedestrian safety

The safety of vulnerable road users, namely pedestrians, in a road-crash scenario with automobiles remains as a vehicle design challenge. A multi-body simulation between pedestrian and vehicle in MADYMO was used to simulate a crash of vehicle front [14 parameters] against 4 different TNO pedestrian models [95th %le M, 50th %le M, 5th %le F, 6 Y.O. Child]. Pedestrian safety was measured using Weighted Injury Cost (WIC). A global optimization was performed using genetic algorithm in order to minimize WIC with geometric constraints on vehicle profile. Within known limitations, at least one pedestrian friendly vehicle shape not resembling any existing vehicle profile was found.

Traffic injuries have been shown by the World Health Organization (WHO) report to be one among the top ten causes of threat to human life around the world. The injuries related to vulnerable road users (VRU), more specifically pedestrian and vehicle collisions have remained higher in developing countries. Studies has highlighted the importance of pedestrian fatalities from vehicles in the urban regions of India. Studies on German In-Depth Accident Study (GIDAS) have provided specific comparison of injury causation on all three categories of VRU with vehicle. The study also points out the role of vehicles shapes on injuries provides relationships between speed of crash to injury severity. A speed of 40 kmph for pedestrian has been suggested and the same was indicated to be a moderate level of threat from crash database analysis.

A VRU crash with vehicle front was set-up with crash initial velocity of 40 kmph. Scenarios with hard braking of vehicle [4.7 m/s2 deceleration taken from autonomous braking trials was considered for this study. Pedestrian models are chosen from available TNO pedestrian ellipsoid models. The kinematic predictive abilities of these models have been used for reconstructing pedestrian crashes have also been validated for head impact velocity and location prediction based on PMHS tests data. The gait position of pedestrian population (3 year old child [3C], 6 year old child [6C], 5th percentile female [5F], 50th percentile male [50M] and 95th percentile male [95M]) considered has been set to 0.25 radians at the hip joints(0.5 radians between the two legs) so as to simulate an approximate walking stance. The focus on this work was to use an approximate walking stance with struck leg forward although more detailed studies have been published on considering variations in gait.

Threat to pedestrian has been measured using population Weighted Injury Cost [WIC]. A higher cost would mean higher threat to pedestrian; hence problem was formulated as a minimization of WIC measure. WIC was calculated as threat measure to whole body; hence WIC was formulated as given below in (1) covering at least one injury measure from major regions of body being injured. An overview of the injury measures and their specific applications can be found.

$$WIC = f(HIC, N_{ij}, (a_{sternum})_{3ms}, FFC, TI)_{pop} \quad (1)$$

WIC - Weighted Injury Cost (USD) for a pedestrian population

HIC - Head Injury Criterion

$(a_{sternum})_{3ms}$ - Linear peak acceleration at sternum for a window of 3mS(m/S2)

FFC - Femur Force Criterion (N)

TI - Tibia Index

WIC measure was calculated based on the outputs from multi-body simulations using MADYMO solver. Batch solver scripts were used in conjunction with OptiSlangTM to read the Ascii input files of Madymo and write back input files for it.

A Real Coded Genetic Algorithm [GA] optimization methodology was chosen. The problem was formulated with 14 input parameters from xml files and two outputs, namely WIC and EIC written by MATLAB in text file was read as output. The following constraint (2) was placed on the shape of the vehicle profile generated to maintain a regular looking bonnet shape.

$$Parameter\_6 - (Parameter\_12 + Parameter\_14 + Parameter\_4) = 0.01\,[m] \quad (2)$$

A constraint handling method based on cliff handling ratio of 10% was used which uses penalty based approach taking into consideration the previous values of the variables. Population size for every generation was chosen as 100. Ranking was selected as Linear and selection method of the best was through Roulette wheel method. The crossover operator selected was Simulated Binary with a probability of 50% and nc = 2 to ensure a uniform distribution in variable values across the range. To prevent the algorithm from getting stuck in a local minimum, mutation was also modelled as constraint adaptive with 20% of the value (after previous trials) and a standard deviation of 0.1. GA process was repeated for 17 generations.

GA based optimization process was chosen to perform a global optimization over the entire design space. Variation of the parameter values across the generations. Initial population showed uniform distribution within the planned maximum and minimum values, the convergence of parameters started beyond 5th generation. The parameters' range varied intermittently after 10th generation. The table also shows the variation of median of the values apart from maxima and minima for every generation. Every blue dot represents a single design parameter and the variation of dots indicates an almost uniform spread across the median value and less number of values at extremes. The spread of at least 10% of values near the extremes can be associated with the action of mutation operators in the GA process.

For every generation of designs generated during the GA optimization process, the minimum value showed an almost constant value till 10th generation and in 11th generation, least value was observed. The process was continued further to explore the design space further. In 17th generation two more minima were observed with value equal to the 11th generation value. Figure B in Appendix shows variation of minimum, median value in every generation to understand the convergence process towards the required minima.

Front end designs generated by GA process were compared with simplified vehicle profiles for a sample of existing vehicle profiles in market. Figure 7 shows the WIC variation for a sample of 16 vehicle profiles from compact segment to SUV in Indian vehicle market along with 2 profiles, one each of SUV and sedan were simplified from shape observed. A sample size of 18 was assumed to be representative of existing vehicles. The maximum observed WIC was for "ALTO" simplified profile [0.48 Million USD] and simplified vehicle profile observed [0.42 Million USD. The minimal WIC observed was for a simplified profile of "ACCORD" of 0.10 Million USD. "41", "1685", "17703" and "1772" represent four profiles extracted from GA optimization process. "41" and "1685" profiles have higher value of WIC of 0.55 and 0.39 Million USD as WIC. "1703" [shape "O1"] and "1772" [shape "O2"] profiles were observed minima with WIC value 0.08 Million, which was lesser than least observed WIC by around 20%.

A GA based methodology using "real-coded" implementation provided better representation of the multi-disciplinary problem of vehicle design for pedestrian safety. Mutation operators with at least 10% standard deviation values were needed to prevent the algorithm from being caught in a local minimum. The study showed that using a single measure for threat to pedestrians, a shape with lesser threat to a pedestrian population can be found. It is concluded that for best pedestrian safety a vehicle front that can accommodate an internal combustion engine for urban applications should have:

- Bonnet leading edge located at a height of 0.82 m from ground
- The structural member for bonnet locking should be around 50 mm behind and 160 mm above the bumper leading edge.
- Bonnet is to have a length of 0.63m with bonnet rear end [bonnet hinges] at 1.21 m from ground.

The study assumes that the vehicle stiffness characteristics remain the same for the different designs. In the future, studies can be taken up to investigate effect of varying stiffness characteristics.

Optimization study on multi-body vehicle-front model for pedestrian safety. Sankara Subramanian H, Chawla A, Mukherjee S, Goehlich D. (2014). *The 16th International conference on Machine Design and Production (UMTIK 2014). Izmir, Turkey.*