A FRAMEWORK FOR EVALUATION OF TRANSPORT DEVELOPMENT AND MANAGEMENT OPTIONS USING POLLUTION PROFILE TECHNIQUE

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ABSTRACT

The conventional transport planning technique is rarely put to a simulation framework to link demand and supply to derive a balance for the purpose of transport system design. A transport or traffic operational plan is, therefore, never examined in respect of advantages it may provide in terms of environmental parameters. For example, the recent trends of building flyovers and bypasses indiscriminately, for every town and city in the country, are to be carefully examined through such a framework for their environmental implications. The intent of such methodology is to save the city environment from any illogical transport developments, as many of those are often triggered by the vested interest groups.

The spatially distributed observations of pollutants across the city of Delhi provide the basis of contouring the pollution levels (for each parameter) by space averaging technique. Nine pollution parameters are observed in three shifts for average values. This can be expanded to hourly distribution of pollutants over the whole city using the hourly observations for 24-hours for selected locations (permanent stations) from limited number of permanent stations. Calibrated models linking traffic in the network (by types of road) and the land uses can be developed which will allow prediction of pollution levels in the same set of locations for projected traffic and corresponding operating speeds. Thus, using the hourly variation of spatially distributed measures of pollution loads, changing pollution profiles for each pollutant can be prepared and traffic planning and management options may be guided.

1. INTRODUCTION

Transport planning, traditionally, has been demand driven and with an inherent philosophy to prescribe infrastructure or services to be added to the system to cope with the present demand or those likely demands of the future. Also, any infrastructure development plan needs an assessment in respect of its potential use by the customers. The methods of such analyses developed in the West have been extra biased towards motorized travel. Thus, it is imperative that transport planning and operational management approaches have been rarely taken with a primary objective of protecting city environments while allowing infrastructure developments. Similarly, most traffic engineering solutions are found to aim at relieving the congestion, but in very large number of such cases the congestion has been found to have migrated spatially to another area. With a gradual shift to transport management through TSM (traffic system management) approaches, existing facilities have been used more intensively for higher throughput covering some concerns for betterment of the environment.

Inverting the transport planning technique one can search for maximum demand that can be served by a given supply level. But, so far, it has never been put to a simulative framework to link demand and supply to derive environmental consequences due to a particular level of supply or modal balance for the purpose of recommending transport system design. A transport or traffic operational plan is never examined in respect of its advantage in keeping the environment clean by reducing the amount of travel in the system and thereby minimising the fuel consumption and greenhouse gas emissions. That would mean a complete evaluation of the transport plans in terms of environmental parameters such as, air pollution, greenhouse gas emissions, noise and safety changes that will be affected by the added infrastructure or operational improvements. For example, the recent trends of building flyovers and urban bypasses for facilitating urban transport should be carefully examined through a simulation of travel pattern with and without these additional infrastructures and derive all the environmental parameters with
present and future traffic. It is doubtful that many of these projects will be proved to be worth of the investment, if examined in terms of environmental objectives.

Any transport infrastructure, whether flyover, traffic signals or even widening of roads is a costly proposition. It is justified only when it is sufficiently proved by analysis that it is going to make a difference in the customer satisfaction in terms of time saving, safety, and improved environment. Thus, it must be made mandatory to have a computer simulation which shall be required to provide the air and noise quality measures as output which have direct bearing on how the urban travel is better managed by the added facility or changed operation. The intention of such a methodology shall be to save the environment from any illogical transport development, which is often triggered by vested interest groups. Thus, transport development will be promoted only through a valid criterion of environment protection.

2. URBAN TRANSPORT AND ENVIRONMENT

Economic affluence and structural changes in the society has led to a higher degree of motorisation in 1990s, particularly in urban India, and consequently, the last decade has seen unprecedented growth of vehicle ownership in India. While the overall countrywide vehicle ownership is only a fraction (0.04 per capita) of what is in the west, the extremely skewed distribution of the vehicle fleet with very high concentration in urban areas, the impact on urban environment is severe. The situation in Delhi is extreme where 10% of the country’s motor vehicles are used, and with vehicle ownership level of 0.35 per capita, it is probably the highest among the cities of the developing world. In last year (one year: 2000) alone 200,000 vehicles were added to the vehicle fleet of Delhi. The vehicle ownership is generally guided by the standard of living and the decent alternatives made available for urban travel. It is very clear that in India the alternative modes of transport for urban areas are never planned or developed. Failing to avail a comfortable public means of travel, the commuters would generally opt for private modes. For that matter, no city or town in India has logical balance of the modal shares of different transport modes. Stopping the growth in motor vehicle use, is no doubt, neither feasible nor desirable, given the economic and other benefits of increased mobility. The challenge is, therefore, to manage the usage of motor vehicles minimising their adverse impacts on environment and on society. Adoption of emission control technologies and new-vehicle emission standards are a necessary but not sufficient condition for achieving desired environment quality in an urban area. A conscious and comprehensive strategy ranging from transport development to its management only will save the urban environment.

Environment policy of a country must have a serious link to the transport planning, operations and management. This is all the more important for the urban areas and particularly the metro cities as it holds the future opportunities for protecting the environment in urban areas. This aspect has not been pursued with any seriousness by the Government, except the recent concerns about fuel quality and vehicle fleet. Though EIA/EIS is a mandatory requirement, it is not yet applied in the way it is required for the urban areas. Simple operational improvements like signal coordination, improved signal timings, and host of others also can provide remarkable advantage in fuel economy, and therefore, reduced vehicle emissions. Therefore, all major investments in transport improvement must be linked to environmental protection by evaluating the project output in terms of environmental parameters.

The transport sector is the second largest consumer (50%) of commercial energy, next only to the industry. But, it ranks first in the consumption of petroleum based energy and consumes almost entire amount (98%) of petroleum products in the form of petrol and diesel. The usage of petroleum energy in transport grew at 1.3 % annually during 1971-1981, while it has grown at 6-7% annually during 1991-1999. Among the various modes of transport, road transport consumes the most petroleum energy. India with a fleet of 50 million motor vehicles, 50% of which are equipped with most inefficient and outdated engine technology as well as over-aged status, does not have much maneuverability. Thus, with 0.4 % of global petroleum reserve and 16.6% of world population, India accounts for 2.8 % of world’s consumption of petroleum products. In just one decade, the fuel efficiency of new cars has increased over old cars by about 60%. However, the rapid increase in the vehicle fleet has counteracted the benefits derived from the improvement in the fuel economy of the vehicles.

3. STUDY AREA AND DATABASE

Delhi, the capital city of India, had the dubious distinction, till very recently, for its notoriously high pollution level. The obvious lower fuel economy in congestion and unusually high degree of private vehicle usage made the city highly polluted towards the second half of the 1990s when Delhi was one of the most polluted cities in the world. In 1998 the concentration of air pollutants grew to a level where
public health guidelines and standards were exceeded in alarming proportions. At that stage, the vehicular pollution alone contributed 75 per cent of the total air pollution load of the city. The broad account of air pollution load in Delhi during 1998-99 is given in Table 1. This shows that without the interventions the pollution had reached an alarming state, which has come down by about 25 per cent immediately with interventions. Practically in 1998, Delhi was approaching to the status of a gas chamber with poisonous gases. The traffic intersections were most critically effected locations – Ashram, ITO, Dhaula Kuan, etc being the “black spots” of highest pollution. Assuming that the Supreme Court did not put its foot down on Delhi’s air pollution debate, and pollution was allowed to grow from 1998 level to 2001 and 2005 unabated without any of the present controls or enforcement, it would have been a disaster.

The city of Delhi has been taken as a case study, for which the data from a recent study, sponsored by the Government of Delhi, collected at 250 locations spatially distributed over the whole city, were used. The city road network with the 250 locations of observations is shown in Figure 1. In all, nine pollution parameters (SPM, PM<sub>10</sub>, SO<sub>2</sub>, NO<sub>x</sub>, CO, CO<sub>2</sub>, Pb, HC, and C<sub>6</sub>H<sub>6</sub>) are observed in three shifts giving average value for each shift (i.e. three eight hourly average values for the day of observation) and their measurement units are shown in Table 2. Also, from other sources like CPCB, the data on hourly variation over 24 hours of the day for some selected pollutants observed in some selected locations are available for similar seasons. These are only six permanent stations for pollution monitoring, which can provide partial pollution data, and their locations are as follows:

(a) Red Fort
(b) Lado Sarai
(c) Chattrasal Stadium
(d) Sarai Kale Khan
(e) Siri Fort
(f) ITO

These locations of permanent monitoring stations are shown in Figure 1 with a different notation. Using the hourly variation data from the permanent monitoring stations, the average values of the pollutants observed for the three shifts in the 250 locations can be converted to 24 hourly variations for all 250 locations under some assumptions. Although, the translation of the hourly variation of selected locations (permanent stations) to all the 250 locations does not provide an accurate estimation of the spatial distribution of pollution levels, the present study analysis aims to demonstrate a philosophy of road traffic related pollution using the pollution profile technique. Thus, using the variation of pollution level over 24 hours with its spatial variations, changing pollution levels both in time and space can be examined for each pollutant.

While the complete analysis for all the pollutants will be beyond the scope of this paper, the hourly variation of pollution level of selected pollutants only (NO<sub>2</sub> and SO<sub>2</sub>) at Red Fort and Sarai Kale Khan (permanent stations) are shown in Figures 2 and 3 respectively as example of variation in time. These plots very clearly show that the pollution loads in any selected location is not uniform throughout the day. Assuming the similarity of variation for other locations in space, it can be assumed for convenience (in the present analysis) that the variation recorded in a permanent monitoring station shall be applicable to several of the short-term measurement stations over a wide area of its influence. This implies that the average measures of eight hourly shifts can therefore be converted to hourly variations for each of the 250 locations using the factors devised from the data for the permanent stations. These can now be used for the simulation in relation to the simultaneously observed level of road traffic and its distribution in the network.

4. TRAVEL ANALYSIS AND SIMULATION

It has been indicated above that in 1998, 75 % of the pollution load in Delhi was due to motorized traffic. Thus it can very easily be concluded that the spread of the traffic in the road network under such situation will be able to explain the pollution intensity as it is spread over space within the city area. No doubt, the significant part of the pollutants from industry and other sources as well as the meteorological effect etc can weaken the argument for relating the pollution level or intensity in various localities of the city strictly to the traffic intensity alone. However, it is believed that error in such formulation will be non-consequential to the purpose of this analysis. This paper and the analysis presented is a part of much bigger project, and this paper only attempts to show the spatial and temporal variations of pollution load in Delhi which is largely due to road traffic.
The observed level of pollution in the form of three eight hourly averages (shift I: 1400-2200; shift II: 2200-0600; and shift III: 0600-1400 hours) in a day for SPM is plotted as intensity contours; and this when plotted as DEM (Digital Elevation Model) will show as pollution profile. The two-dimensional plots of pollution intensity in Delhi for SPM are shown in Figures 4 to 6 for the three periods of the day using the average measures. Similarly, the pollution intensity in Delhi in respect of NOx is shown in Figures 7 to 9.

The network traffic in terms of link volumes (in terms of categorised vehicle types) and their operating speeds can be related to the observed pollution level in the area in terms of different pollutants by a reasonable model. A linear or non-linear model can be calibrated using the observed pollution level and traffic so that this can be used for predicting the level of pollution expected from a higher level of traffic with different speed. Based on the data available, the models may be developed for different categories of road and land uses in a city.

As discussed in section 3 above, 8-hourly averages observed for 250 locations can be converted to hourly data using the hourly observations of the pollutants recorded at the permanent stations without loss of any generality. The NOx levels observed in 250 locations during shift III (i.e. 0600-1400 hours) are converted to separate hourly values for the eight hours of the shift and plotted as intensity profiles as shown in Figure 10. The figure only shows the time dependent variation of the pollution level in various areas of the city. These hourly profiles, when prepared for all 24 hours, can also be seen in animation to give a clue to the changes that takes place over the day to suggest the planning and management options.

4.1 Transport Development Planning
All transport development planning in and around a city are taken up mostly with traffic objectives only. Thus, if the cities is congested with external traffic, which does not have any business in the city, and are bypassable, the city bypass is recommended. Although the economic and financial analysis for such projects take account of relief in congestion and improvement in speed etc within the city, they never get evaluated in terms of reduction in pollution and environmental hazards. Generally the benefits in traffic movement within the city due to an enhanced or new facility (like the bypass) will be determined by a distribution-modal split-assignment system of transport planning model. This simulation of traffic spread in the network can be linked to the corresponding pollutant loads through the models calibrated earlier. Thus, any proposed development in the network can be easily evaluated with the prediction of change in pollution profile due to the proposed improvement. For example, the Ring Road in Delhi, a major internal corridor of travel, has been provided with series of flyovers in last two years in an indiscriminate manner without a proper evaluation of the likely improvement in traffic operations as well as pollution levels along that corridor. The 48.5 kilometers long ring road has 92 road junctions, out of which 10 are provided with flyovers and 2 are under construction. Thus, 80 intersection will be without any grade separation, and are with at-grade signalized or uncontrolled intersection. It would have been an appropriate strategy to evaluate the strategy of building flyovers before adopting the same. Similarly, due to the absence of a bypass, all the traffic of the surrounding states pass through Delhi as they have to travel through the nine major highways which converge into the city. The construction of a suitable bypass can be easily simulated to show the relief for the city both in terms of congestion as well as pollution.

4.2 Planning for Traffic Management
The management of traffic in a city like Delhi is not a simple task. The unusually high usage of Personalised motor vehicles puts a special problem for the traffic managers of the city. Further, in spite of the wide roads, the mixed traffic, poor traffic discipline and enforcement makes the problem even worse. However, TSM methodology provides many opportunities to maximize the throughput in the system by using the facilities optimally. But, any such significant network level management strategy in terms of signal coordination, one-way street system or a set of geometric improvements, etc., is to be evaluated in terms of both traffic as well as environmental parameters. The network level signal coordination in the form of ATC for 50 signals is in use in Delhi. But, such a system could be easily simulated as discussed above to indicate the benefits expected including those related to advantages in reduction of pollution levels in the implementation area.

5. CONCLUSION
The traditional transport planning and management can be easily enhanced to encompass the compliance of environmental regulation (standards) while testing or evaluating the alternative options using a simulative framework. Unless a development or management strategy does not satisfy the
environmental parameters, it must not be implemented only with the traffic objectives. Due to the peaking
nature of the urban travel, usually there is spare capacity during off-peak period. Hourly variation of the
pollution profile of an urban area, in this context, provides the opportunity to explore the possibility of
accommodating additional traffic during the lean traffic hours of the day. Thus, the management of the
city traffic must be guided by the total pollution scenario in terms detailed pollution profiles of the city.

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### TABLE 1 Estimated Vehicular Pollution in Delhi

<table>
<thead>
<tr>
<th>Pollutants</th>
<th>Pollution Load in Thousand Tonnes</th>
<th>Without Measures</th>
<th>With Measures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon Monoxide (CO)</td>
<td>243</td>
<td>373</td>
<td>451</td>
</tr>
<tr>
<td>Hydrocarbons (HC)</td>
<td>82</td>
<td>123</td>
<td>148</td>
</tr>
<tr>
<td>Nitrogen Oxides (NOx)</td>
<td>139</td>
<td>208</td>
<td>248</td>
</tr>
<tr>
<td>Sulphur Dioxide (SO$_2$)</td>
<td>10</td>
<td>15</td>
<td>17</td>
</tr>
<tr>
<td>Lead (Lb)</td>
<td>0.19</td>
<td>0.259</td>
<td>0.362</td>
</tr>
<tr>
<td>Particulate Matter (PM)</td>
<td>19</td>
<td>28</td>
<td>33</td>
</tr>
<tr>
<td>Total Pollution Load</td>
<td>394</td>
<td>747</td>
<td>897</td>
</tr>
<tr>
<td>Emission Load in tonnes per day (TPD)</td>
<td>1351</td>
<td>2047</td>
<td>2459</td>
</tr>
</tbody>
</table>
### TABLE 2 Pollution Measurement in 250 Locations in Delhi

<table>
<thead>
<tr>
<th>Pollutant</th>
<th>Description</th>
<th>Measurement Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>SPM</td>
<td>Suspended Particulate Matter</td>
<td>µg/cum</td>
</tr>
<tr>
<td>PM$_{10}$</td>
<td>Respirable Particulate Matter, 10mm</td>
<td>µg/cum</td>
</tr>
<tr>
<td>SO$_2$</td>
<td>Sulphur dioxide</td>
<td>µg/cum</td>
</tr>
<tr>
<td>NOx</td>
<td>Oxides of Nitrogen</td>
<td>µg/cum</td>
</tr>
<tr>
<td>CO</td>
<td>Carbon Monoxide</td>
<td>mg/cum</td>
</tr>
<tr>
<td>CO$_2$</td>
<td>Carbon dioxide</td>
<td>mg/cum</td>
</tr>
<tr>
<td>Pb</td>
<td>Lead</td>
<td>µg/cum</td>
</tr>
<tr>
<td>HC</td>
<td>Hydrocarbon as CH$_4$</td>
<td>ppm</td>
</tr>
<tr>
<td>C$_6$H$_6$</td>
<td>Benzene</td>
<td>mg/cum</td>
</tr>
</tbody>
</table>
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(Shift – III: 0600 to 1400Hrs)
FIGURE 10  Hourly Intensity Profile of NO\textsubscript{X} (Shift – III)