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Analysis of Transportation Policies on Health and Environment in Delhi, India

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Abstract—*For many countries like India the transport sector is the most rapidly growing energy end- use category. Choices made now will have impacts lasting well into the middle of the 21stcentury. The desire for personal mobility in urban areas, typically by means of personal- use vehicles, will comprise much of growing transportation energy demand. Automobile emissions are the fastest increasing source of urban air pollution in most developing cities. In India most urban areas including Delhi already have major air pollution problems that could be greatly exacerbated if growth of the transport sector is managed unwisely. Delhi's spatial growth over the last 25 years has been rapid and urban sprawl is contributing to increasing travel demand. We propose the development of decision support tools for understanding the different ways to manage this sprawl and plan for a better Delhi in years to come. This paper focuses on a vehicular air pollution information system, to provide some insight about the key parameters of the transport system of Delhi now and in the future.*

Keywords*: air quality, transportation planning, decision support systems, GIS, land use planning*

Urban Transportation Planning for Air Quality Management

The number of vehicles in India has increased by 11.5 times from 1.9 millions in 1970 to 21 millions in 1990. The number of vehicles per 1000 people has increased from 3.4 to 25.31 in the same time, with estimates of 43 vehicles per 1000 people for year 2001. The number of registered vehicles is maintaining its increasing trend with the growth from 25.2 millions in 1993 to 33.85 millions in 1996.

This accelerated growth of the transportation sector in India will have the greatest impact on large cities where development is occurring in a fast and imperfect form. The main reasons for the big cities to be most affected from this development will be the large population growth and the intensification of employment opportunities in such areas which will draw more people from the rural areas into the urban areas.

India's GDP has increased 2.5 times over the past two decades while vehicular pollution increased by 8 times. Every time GDP doubles in India, air pollution rises by 8 times, mostly as a result of increased emissions from the growing transportation sector. Auto emissions currently account for approximately 70% of air pollution .Turnover period of vehicles is about 20 years compared to 6-8 years in developed countries which adds onto the air quality deterioration.

Delhi has 1% of the entire country's population but 10% of the total vehicles registered in India. Personal vehicles account for almost 90% of all vehicles in Delhi - largely with single occupancy, and are therefore not very efficient as a transport mode. The total number of vehicles per 1000 people in 1998 was 238.

Although Delhi has one of the highest per capita road lengths and lowest number of vehicles per unit road length when compared with large cities around the world, it is still the most congested city in India Delhi has the highest road length in India. And its roads, if modern traffic management is applied, can accommodate 2-3 times the existing number of vehicles Therefore, in order to reduce traffic congestion in Delhi, the use of well-designed traffic management control options are essential.

As a first step to study urban transport, we have developed a spreadsheet based vehicular air pollution information system for Delhi .Our final goal is to create an optimization model, which will be used as a decision support system with a user-friendly graphic interface that will assess the optimal transportation mix to meet the turnover (passenger-km demand), environmental goals, and other constraints through a variety of policy options at a minimum cost. The results from these applications will also be linked to a GIS for Delhi for a visual representation and the evaluation of the effects of land use changes on air quality. Exposure and health impacts under each scenario will also be mapped in this GIS for Delhi.

The Spreadsheet Vehicular Air Pollution Information System

1. INTRODUCTION

This spreadsheet model which was developed for Delhi can also be applied to any other city provided with the necessary input data. We have represented the vehicle fleet in Delhi by 6 different vehicle types: cars/jeeps/station wagons (categorized as cars), two wheelers, three wheelers (auto rickshaws), taxis, buses, and trucks. The model includes data and information from 1985 to 2020 and projects the number of vehicles, average vehicle fuel efficiencies (km/lt), average vehicle emission factors (g/km), age distribution of vehicles in each year, vehicle kilometers traveled per day, fuel consumption, and emissions for the 8 chosen pollutants (CO, NO_x, HC, Pb, TSP, PM10, SO_2, CO_2).

The spreadsheet model enables officials in Delhi to keep track of the vehicle population, including its age and model type; to monitor and calculate the average emission factors for different vehicle categories and pollutants; and to evaluate different emission control technologies including their effectiveness in emission reduction and cost. After the addition of the necessary input data, appropriate control options and/or policies for the future can be assessed by the model and the changes in the predictions of all the parameters could be observed. Also, health impacts estimation from vehicular emissions can be made by exposure assessment. Observing daily patterns of exposure of people can also provide information about which control options should be enforced and when.

The spreadsheet model for Delhi shows that the assumed growth of automobiles is from around 850,000 in 2000 to more than 5.8 millions in 2020 with the total number of vehicles surpassing 13.5 millions in 2020 (see table 1). It cannot be imagined where all these vehicles could be fit in the existing road network. Congestion becomes an increasingly important problem and average round trip commute times rise from slightly more than 60 minutes in 2000 to about 195 minutes in 2020. According to World Health Organization (WHO) names Delhi as the 5th most polluted city in the world in terms of suspended particulate matter . Particle levels in Delhi consistently remain 3 to 5 times the national standards and maximum levels have even reached 8 times the standards during the winter of 1998. Levels of PM10 in a residential area in Delhi (ROHINI) have attained 5 times the limits in October 20015 (CSE 2001).

Approximately, 80% of CO, 70% of NO_x, and 95% of HC emissions have been estimated to come from mobile sources in Delhi. In our study, when congestion effects on emissions factors are considered through lowered speeds, concentrations resulting from motor vehicle emissions more than triples for CO and roughly doubles for TSP and PM10 from 2000 to 2020, further worsening air quality in Delhi . SO_2 emissions decrease almost by 73%, even though the number of vehicles increase by more than 4 times from 2000 to 2020, due to the subsequent implementation of strict fuel quality standards for sulfur content in gasoline and diesel along with Euro emissions standards. Given these levels of emissions, our preliminary estimates are that the damages due to the health.

DELHI TRANSPORTATION SYSTEM

The rapid growth of population and imbalance in the distribution of income among its people has created massive chaos in Delhi's transportation system. Delhi's large rail network (120km) is practically not used and all transport needs are being met by roads. Cars, taxis, buses, autorickshaws as well as bicycles, tricycles, handcarts, bullock carts, animals, and pedestrians share the same road space with no traffic segregation. Delhi has two ring roads and one ring railroad. Five railroads and nine roads, of which five are national highways, intersect in Delhi leading to high amounts of congestion in the city. Also, Delhi vehicles still lag behind European standards. As a result Delhi became one of the top ten most polluted cities in the world .

When compared with other big cities in the world, Delhi has less automobile usage, no subway or light rail passenger transport, and much more bus passenger transport and non-motorized vehicle usage (mainly walking and bicycling). Also, the share of air pollutant emissions from the mobile sector is lower in Delhi compared to more developed cities. The main reasons for this are that the transportation sector is rapidly growing now and that industries / stationary sources of air pollution are out in the suburb areas in more developed cities, whereas they are still scattered all over the whole area of Delhi.

In 1995 the total number of vehicles in Delhi was slightly above 2 millions of which cars and two wheelers made up about 25% and 64% respectively (see table 1). Although, buses made up only 1.2% of the vehicle fleet in 1995, they contributed 7% and 60% to vehicle km traveled and passenger km traveled in the same year. The spreadsheet reports a great increase in the number of cars, from around 535,000 in 1995 to more than 5.8 millions in year 2020, accounting for 43% of the total number of vehicles in Delhi in that year. The other mode of transportation that continues to make up the greatest proportion of the vehicle fleet in Delhi (about 52% in 2020) is the two wheelers, reaching more than 7 million in 2020. The rest of the vehicle fleet composition in 2020 is made up of 98,282 taxis, 121,510 autorickshaws, 53,569 buses, and 406,557 trucks

Fig. 1 shows the number of vehicles of different ages in each year from 1995 to 2020. Based on Supreme Court orders (1997-2001), the retirement age for different vehicles in different years changes until 2001 and then is maintained at the same level into the future. The constant scrap rate that the model uses for each vehicle after year 2000 is 25 years for cars, 15 years for two wheelers, 10 years for auto rickshaws, 15 years for taxis, 8 years for buses, and 12 years for trucks. The projections illustrate that the vehicle fleet becomes newer and cleaner because of the regulations enforced for the new vehicle emission standards.

Table 1

		1995	**2**
# of vehicles	Total	2,076,120	2,9

% of vehicles	Cars	25.77	29.05	43.02
	two wheelers	64.02	62.24	51.97
	Autorickshaws	2.95	2.36	0.90
	Taxis	0.46	0.40	0.73
	Buses	1.18	0.55	0.40
	trucks	5.62	5.30	3.00
PKM traveled	Total (bpkm/yr)	95	97	354
% of PKM by vehicle	cars	12.5	18.56	35.59
	two wheelers	9.37	12.37	12.71
	autorickshaws	5.21	5.15	2.54
	taxis	1.04	1.03	1.98
	buses	59.38	46.39	35.32
	trucks	12.50	16.50	11.86

Delhi has taken many actions so far to curb air pollution from motor vehicles and develop a sustainable transportation sector. Delhi has introduced Euro II standards for all new cars in April 2000 and Euro I for all new LDV and HDV. Leaded gasoline was phased out in September 1998 and catalysts were mandated on all new cars in October 1998. Sulfur content of diesel and gasoline were reduced to 0.05% by weight in April 2000. New retirement ages for vehicles as mentioned above were introduced. The use of alternative fuels and especially CNG buses are being pushed but the results of the implementation of such decisions are rather uncertain. Delhi Metro Rail Corporation is working on a large project for the implementation of Delhi MRTS which in its first phase plans to build an 11km of subway and 41km of surface and elevated rail system by 2005 in order to reduce congestion, air pollution, and accidents and save fuel and space (http://www.delhimetrorail.com). The full system is supposed to be finished by 2021 with 34.5km of subway, 35.5km elevated and 111km surface rail, and 17.5km dedicated busway with a total system length of 198.5km. On the traffic demand management side, the Supreme Court limited the monthly number of car registration to 1500 (previously 4000 vehicles per month were being sold). Finally, goods vehicles were restricted during the day within the city limits (December 1997).

Due to the uncertainties related to the implementation of alternative fuel vehicles and traffic demand management options, in this spreadsheet model we have focused on the technological improvements of vehicle engine designs to meet certain emissions standards and fuel quality improvements to investigate their impact on air pollution from mobile sources. In addition to Delhi being under Euro II standards for all new cars (2000), the model assumes that Euro III, US Tier II, and Euro IV standards will be enforced for all new vehicles by 2005, 2010, and 2015 respectively. The corresponding fuel qualities for sulphur content of gasoline and diesel are also required to comply with the Euro norms accordingly.

There are four cases considered for managing transportation in Delhi in this model:

Case1: Continuous technological advancement to meet fuel efficiency, emissions factors, and fuel quality improvements until 2020.

Case 2: Stop technological advancement in year 2000 and keep 2000 technologies into the future.

Case 3: Case 1 with the effects of reduced speeds and congestion on fuel efficiencies and emissions factors.

Case 4: Case 3 with year 2000's speeds kept constant into the future.

The parameters used in the calculation of average emission factors in a year include speed, new vehicle emission factors and average vehicle emission factors from the previous year, number of old and new vehicles in that year. Average vehicle emission factors for 1995 are given and new vehicle emission factors are known for the future based on the spreadsheet's assumption about the implementation of strict European and US standards. Then, knowing the amount of new vehicles coming into the fleet, the number of vehicles being scrapped based on vehicle retirement ages, and their corresponding average and new vehicle emission standards, the average vehicle emission factors are calculated for each year.

However, many other factors will influence the emission factors such as the amount and quality of road infrastructure available, use of control options, age of vehicles, fuel quality, and speeds. The first set of emission factors generated was based on the 1995 average speed level (31km/hr). Using our knowledge of the number of vehicles and average speeds in other years, estimates for the average speed levels for all the years are obtained using regression techniques. Also, using the polynomial relationships of speed with emission factors of different types of vehicles (as average speeds increase emissions factors decrease), emission factors are calculated for the speeds of each year and then they are used in scaling the emission factors obtained in the first step using 1995 as the base year, to get the final emissions factors trend from 1995 to 2020 for all types of vehicles and pollutants (CO, NO_x, and HC).

Since speed affects CO emission factors most among CO, HC, and NO_x, and at a much higher level than the other pollutants, the regulations on new vehicle emission standards are easily and quickly negated by the reduced speeds for this pollutant's emission factor trend over time. After around year 2006, average emission factors increase because the total number of vehicles becomes very high and therefore average speeds decrease a lot resulting in a large increase in the average vehicle emission factors that cannot be offset by the better new vehicle emission factors for the small amount of new vehicles that are added to the fleet (see Fig. 3 for an example of emission factor trend – CO).

The change of fuel efficiencies over time for different types of vehicles in Delhi were calculated based on 1995 average fuel efficiencies and improvements over the years in vehicle technologies, again finally being scaled up by using fuel efficiencies calculated from the speed versus fuel efficiency relationship (fuel efficiencies increase as speeds increase) using 1995 as the base year for scaling. The results show that improvements in vehicle technologies are not sufficient to overcome the adverse effects of reduced speeds. Finally, SO_2, TSP, PM10, and CO_2 emission factors are calculated as the weighted average of new vehicle and old vehicle emissions factors for these pollutants. Then these average emissions factors are scaled up based on fuel efficiencies, therefore, revealing the effects of reduced overall fuel efficiencies from reduced speed levels on the trends of these pollutants emissions factors. Increasing CO_2 emissions factors can be observed from after around 2010 but a drastic increase in TSP and PM10 emission factors can be seen starting year 2015. This is because the last improvement on emissions factors for these pollutants occur in 2015 and then the huge increase in the number of vehicles results in a great drop in speeds and consequently in fuel efficiencies which result in these increasing trends of emission factors. SO_2 emission factors, on the other hand, continue to decrease due to the very strict fuel quality standards being enforced that lowers the sulfur content of gasoline and diesel to 0.005% by weight by 2015.

Using fuel efficiencies, emission factors, retirement ages, vehicle growth rates, number of vehicles, and vehicle kilometers traveled, the amount of fuel consumption and emissions from motor vehicles can be calculated. The amount of fuel consumption increases by 5.7 times from 1995 to 2020 (from 1,602 million liters/year to 9,123 million liters/year – see table 2). The energy supply deficit of India has been increasing since 1985. India already imports about twice as much as the amount of its domestic oil production. As a result of the discovery of most of India's easily recoverable oil, low recovery rates of Indian oil fields (30% on average), and the rapidly growing economy, India will have a very hard time keeping up with the demand for oil to feed its growing transportation sector.

A very simple rollback method is used to calculate air quality concentrations resulting from these emissions, based on relationships obtained for emissions versus concentration where data was available for both in previous years. The results for concentrations resulting only from vehicular emissions show that CO concentration more than triples, and NO_x and PM10 concentrations increase by about 8% and 91%, respectively, in 2020 compared to 2000. Finally, SO_2 concentration is reduced by more than 70%. (See table 2)

The emissions predicted by the spreadsheet model assume that all necessary technological advances will be incorporated in the new vehicles that should have the new vehicle emissions standards demanded by the regulations. The discussions above focused on Case 3 results as mentioned earlier. If we were able to keep year 2000 average speed (21.2km/hr) constant into the future with the same number of vehicle growth rates, assuming that some traffic management options will be used to attain this goal, the fuel consumption in 2020.

In order to evaluate the economic consequences of transportation we need to calculate the value of externalities from the transportation sector in Delhi to assess the relative magnitudes of the different components. Two main externalities are considered in this section: production loss due to time spent in traffic and health damages due to air pollution resulting from vehicular emissions. Furthermore, transportation sector fuel costs are calculated.

Parameters required for the calculation of annual production loss due to time spent in traffic are average wage levels, economic growth rate, workdays in a year, work hours per day, valuation of an hour of time in traffic, average speed, round trip commute time per day per commuter, and number of people commuting. Time spent in traffic for commuting increases a lot over time due to the increased number of vehicles on roads and reduced speeds. Parameters required for fuel cost calculations are average speed, fuel efficiencies, number of vehicles, vehicle kilometers traveled, economic growth rate, and fuel prices.

(Case 3 – Case 1). If Delhi acts so that year 2000's speed can be maintained constant into the future then $4,147.79 million per year (Case 3 – Case 4) in health costs could be saved in 2020. This shows that although technological improvements are necessary to reduce emissions from vehicles, measures directed at reducing congestion are even more crucial in lowering vehicular emissions and their health impacts.

An important outcome of these calculations is that while health costs and fuel costs are by far larger than the value of time in years 1995 and 2000, the value of time is the one increasing most from 2000 to 2020 and it becomes the largest component of these costs by year 2020. The reasons for this are that increased number of vehicles and reduced speeds on roads due to the rapid growth of the transportation sector increases the time spent in traffic and increased valuation of time due to higher incomes resulting from the fast economic growth in India increases congestion costs.

Finally, costs of congestion resulting from delay time in traffic, the amount of fuel wasted, and increased health impacts are calculated to show the possible reductions in these costs that can be attained by increasing speeds and reducing congestion

Conclusions from the Spreadsheet Model

The spreadsheet model results show that the transportation sector in Delhi is developing very fast and if uncontrolled the results could be disastrous. The number of vehicles is expected to grow by more than 4.6 times from 2000 to 2020 and total vehicular emissions will approximately become 9 times as much in the same period of time. As a result the air quality will be profoundly worsened. Therefore, technological improvements alone to make each vehicle cleaner will not be enough to solve Delhi's air pollution problems resulting from vehicular emissions. Also, although currently value of time spent in traffic is low compared to the health damages and fuel costs of Delhi's transportation system, if careful land use planning and traffic management are not implemented these costs will become very significant and the highest among the three damages mentioned. The costs of congestion (from delay time in traffic, fuel wasted, and health costs) are very high and increasing speeds will achieve great savings.

The aim of transportation planning should be directed at efficient passenger transport rather than vehicle transport because that is the only way the city will be able to meet the growing transportation demand in a sustainable manner. For this purpose, energy use per passenger-km and emissions per passenger-km will be good parameters to consider in order to frame the action plan that will enable the city's future transportation system meet the demand. Mass rapid transit systems such as buses, subway and light rail systems are the most efficient modes of transport that have low levels for these parameters. Maintaining a friendly and safe environment for pedestrians and non-motorized vehicles is also very important. These parameters are included in the optimization model being developed as part of the proposed integrated decision support system.

2. AN OPTIMIZATION MODEL

Motivation for the Optimization Model

In most developed countries, total energy demand is distributed in roughly equal proportions to three categories - transportation, industrial, and household and commercial sectors. Most developing countries are transportation-poor, with about ten percent of total energy demand from this

3. GIS MODEL

Geographical Information systems (GIS) can be an important element in carrying out research which involves spatial data. GIS can be used for input, storage, analysis and visualization of spatial data. Most factors that are used to predict air quality such as terrain, traffic, concentrations of pollutants, land use, meteorological data etc can be obtained as geo-referenced data. These factors can be combined to study various aspects of air quality management in Delhi:

4. SUMMARY

Clearly the results from the spreadsheet model indicates that Delhi, as well as other similar cities and surrounding regions of India and other emerging markets, need a broad, systematic but practical assessment of the conventional concepts of personal-use transportation. Even though these models are preliminary, we believe that strong conclusions can be drawn from them, namely; technical advancement to improve vehicle technologies and fuel quality alone will not be enough to solve Delhi's air pollution and congestion problems resulting from the rapidly growing transportation sector, and that travel demand management and land use planning are essential to attain a sustainable transportation system in Delhi.

To address these problems more directly we plan to develop models that will take the predicted demand for person-kilometers traveled as the primary input, and seek the mostcost-effective mix of transportation options to meet this demand, subject to a variety of adjustable policy, technology, and environmental parameters. To do this we need to go beyond the spreadsheet model to include the optimization model, which in turn needs to be linked to the spatial database through GIS and land use/transport models. The resulting spatial decision support system could be a useful tool for the various agencies that are responsible for planning for the Delhi region of 2025.

5. ABBREVATIONS

CNG: compressed natural gas

CO: carbon monoxide

CO_2: carbon dioxide

DALYs: disability adjusted life years g/km: grams per kilometer

GDP: Gross Domestic Product

GIS: Geographic Information Systems

GNP: Gross Natural Product

HC: hydrocarbons

MRTS: Mass Rapid Transit System

MST: Ministry of Surface Transport

NO_x: nitrogen dioxide

NV: number of vehicles Pb: lead

PM10: particulate matter less than 10 micron in diameter PKM: passenger kilometers

SO_2: sulphur dioxide

TERI: Tata Energy Research Institute TSP: total suspended particulates

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