Transportation and Environment:

Problems in Delhi and Beijing

Peter Rogers, Sumeeta Srinivasan, and Karolin Kokaz

2 March, 2001

World Bank Seminar
GOALS

• Put new emission standards in perspective
• Show relative impacts of health and congestion benefits
• Show need to integrate land-use planning and traffic management into environmental management
• Show usefulness of Decision Support models in data poor situations
Outline

• Substantive Work
• Analytical Work

• Comparative Statistics
• GIS
  – Srinivasan

• Delhi Studies
  – Kokaz, Harshadeep, Rogers
• Simulation
  – Harhadeep, Kokaz
• Optimization
  – Kokaz

• Beijing Studies
  – Kokaz, Liu, Rogers
• City comparison
• Some comments on application of DSMs
• Recently with the population growth and economic expansion, the number of vehicles has been increasing rapidly in China and India.

• Automobile emissions are the most rapidly growing source of urban air pollution in most developing cities.

• These emissions contribute to a disproportionate amount to human exposure. And also, the highest polluting vehicles provide an huge amount of these total emissions.

• Therefore, targeting vehicular pollution control may be more cost effective than the industrial sector.

• The following slides include some international comparisons in transport system characteristics of different cities in the world, the description of Delhi’s and Beijing’s transportation sector and its effect on the environment.
Share of Air Pollutant Emissions from the Mobile Sector

<table>
<thead>
<tr>
<th></th>
<th>CO</th>
<th>HC</th>
<th>NO\textsubscript{x}</th>
<th>SO\textsubscript{2}</th>
<th>PM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mexico, 1994</td>
<td>100%</td>
<td>53.3%</td>
<td>70%</td>
<td>26.5%</td>
<td>4.3%</td>
</tr>
<tr>
<td>Santiago, 1992</td>
<td>94.2%</td>
<td>82.7%</td>
<td>84.6%</td>
<td>24%</td>
<td>11.5%</td>
</tr>
<tr>
<td>São Paulo, 1995</td>
<td>96.4%</td>
<td>90.9%</td>
<td>97.3%</td>
<td>85.5%</td>
<td>42.7%</td>
</tr>
<tr>
<td>Rio de Janeiro, 1978</td>
<td>96.4%</td>
<td>73.2%</td>
<td>69.6%</td>
<td>9.5%</td>
<td>3.5%</td>
</tr>
<tr>
<td>Beijing, 1992</td>
<td>63.4%</td>
<td>73.5%</td>
<td>21.7%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Beijing, 1995</td>
<td>86.2%</td>
<td>49.1%</td>
<td>10%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Delhi, 1995</td>
<td>80.5%</td>
<td>95.2%</td>
<td>69.4%</td>
<td>13%</td>
<td>12%</td>
</tr>
</tbody>
</table>

As the polluting industries which are scattered all around the urban area in Delhi and Beijing move out to the suburban areas and the transportation sector continues to grow, the share of mobile sources emissions will keep on rising.


Data for Beijing comes from the report titled *China’s Strategies for Controlling Motor Vehicle Emissions, 1997.*
Comparison of passenger trip mix among big cities in the world

<table>
<thead>
<tr>
<th></th>
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<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Tokyo</td>
<td>100%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Paris</td>
<td>100%</td>
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<td></td>
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<tr>
<td>London</td>
<td>100%</td>
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<td></td>
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<td></td>
<td></td>
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<tr>
<td>New York</td>
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<td></td>
</tr>
<tr>
<td>Bangkok</td>
<td>100%</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Seoul</td>
<td>100%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mexico City</td>
<td>100%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Beijing</td>
<td>100%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Delhi, 1994

<table>
<thead>
<tr>
<th>Mode</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Buses</td>
<td>62.00%</td>
</tr>
<tr>
<td>Cars</td>
<td>6.94%</td>
</tr>
<tr>
<td>Light Rail/Subway</td>
<td>0.00%</td>
</tr>
<tr>
<td>MC</td>
<td>17.59%</td>
</tr>
<tr>
<td>NMV</td>
<td>6.61%</td>
</tr>
<tr>
<td>Others</td>
<td>6.86%</td>
</tr>
</tbody>
</table>

Others:

<table>
<thead>
<tr>
<th>Mode</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Autorickshaws</td>
<td>2.80%</td>
</tr>
<tr>
<td>Taxis</td>
<td>0.06%</td>
</tr>
<tr>
<td>Rail</td>
<td>0.38%</td>
</tr>
<tr>
<td>Others</td>
<td>3.62%</td>
</tr>
</tbody>
</table>
Comparison of Vehicle Ownership and Pollution in Big Cities in the World

Data for Delhi vehicle number is in 1997, NOx pollution is monthly average in 1998. Data for Beijing is in 1998. Others are in 1990.
## Comparison of Road Infrastructure & # of Vehicles in Big Cities in the World

<table>
<thead>
<tr>
<th></th>
<th>Road Supply (m/person)</th>
<th>Total Vehicles per km of Road</th>
</tr>
</thead>
<tbody>
<tr>
<td>New York (1991)</td>
<td>4.70</td>
<td>99</td>
</tr>
<tr>
<td>Paris (1991)</td>
<td>0.90</td>
<td>410</td>
</tr>
<tr>
<td>London (1991)</td>
<td>1.90</td>
<td>186</td>
</tr>
<tr>
<td>Tokyo (1991)</td>
<td>1.90</td>
<td>140</td>
</tr>
<tr>
<td>Beijing (1995)</td>
<td>0.94</td>
<td>50</td>
</tr>
<tr>
<td>Delhi (1992)</td>
<td>2.17</td>
<td>90</td>
</tr>
</tbody>
</table>

Air Pollution in Different Cities in the World in 1995
annual average ($\mu$g/m$^3$)

<table>
<thead>
<tr>
<th>City</th>
<th>TSP</th>
<th>SO$_2$</th>
<th>NO$_2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beijing</td>
<td>377</td>
<td>90</td>
<td>122</td>
</tr>
<tr>
<td>Delhi</td>
<td>415</td>
<td>24</td>
<td>41</td>
</tr>
<tr>
<td>Tokyo</td>
<td>49</td>
<td>18</td>
<td>68</td>
</tr>
<tr>
<td>Mexico City</td>
<td>279</td>
<td>74</td>
<td>130</td>
</tr>
<tr>
<td>London</td>
<td>25</td>
<td>77</td>
<td></td>
</tr>
<tr>
<td>New York</td>
<td>26</td>
<td></td>
<td>79</td>
</tr>
<tr>
<td>Los Angeles</td>
<td>9</td>
<td></td>
<td>74</td>
</tr>
</tbody>
</table>
Outline

• New Delhi – an overview of plans and infrastructure
• Creating a database to understand transportation, land use and air quality management in New Delhi
• Land use and transportation planning in New Delhi
• Air quality issues in New Delhi
New Delhi, India

• 1 meter resolution black-and-white image of the Government District, New Delhi.
• IKONOS satellite collected the image on October 10, 1999.
Historical images of Delhi - 1

Seven cities of Delhi:
Lalkot,
Siri,
Tughlakabad,
Jahanpanah,
Firuzabad,
Sher Shahi (Purana Quila),
Shahjahanabad

Sources: A. K. Jain, The making of a metropolis
Historical images of Delhi - 2

Historic walled city of Delhi

- Built in 1638 A.D. by Shahjahan
- Fortified with wall of 6 km circumference

Sources: Breese 1966
Historical images of Delhi - 3

- Came into existence in 1911; construction completed in 1931
- Planned on a hexagonal grid system
- Dominated by wide vistas, enormous buildings and large gardens

Sources: A. K. Jain, *The making of a metropolis*
Land use change in New Delhi

Delhi 1974
Lard cover derived from Landsat MSS
acquired May 8, 1974

Delhi 1999
Lard cover derived from Landsat TM
acquired April 21, 1999
Database development

• Sharing of publicly available data from the local level agencies such as
  – DDA
  – NDMC

• State level agencies such as
  – Government Ministries
  – Town and Country Planning Organization

• Central Government Agencies such as the Central Road Research Institute,

• And other concerned data users and providers (Academic institutions, NGO, TERI)
Land use planning for New Delhi

• Who plans for
  – the City of Delhi?
  – the NCT?
  – the NCR?

• Integrated Land use and transportation planning is vital in cities with the growth rate that we can see in Delhi. Successful cases of such integration include:
  – Curitiba, Brazil
  – Portland, Oregon, USA

• Note that the variety of land uses is high in New Delhi
Modern Delhi

• Became state in 1992
• 2000 Population: 13,964,000
• Key bodies for all municipal services:
  • MCD (Municipal Corporation of Delhi)
  • NDMC (New Delhi Municipal Committee)
  • Delhi Cantonment Board
• Has 70-member legislative assembly and a 7-member council of ministers
WHO announces Delhi to be one of the top ten most polluted cities in the world!

• 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.
• Particulate pollution kills 1 person per hour in Delhi
• WHO: Delhi is the 4th most polluted city in the world in terms of SPM.
• One out of two policemen suffers from respiratory diseases and one in every four have been diagnosed positive for initial symptoms of tuberculosis (Times of India, October 1998).
• If air pollution is reduced to WHO annual average standards then several thousand premature deaths, 4 million hospital admissions and sickness requiring medical treatment, and 242 million incidences of minor sicknesses (including RADs and RSDs) could be avoided in Delhi.

Infrastructure issues - Traffic corridors

Source: www.isl.uni-karlsruhe.de/vrl/resp/delhi/respdwww/c
overpage.html
Traffic problem areas

Source: www.isl.uni-karlsruhe.de/vrl/resp/delhi/respdww/coverpage.html
Traffic accidents

Source: www.isl.uni-karlsruhe.de/vrl/resp/delhi/respdww/coverpage.html
Air quality in New Delhi

- A view of changes in SPM over 22 months
  Jan 1999 - Oct 2000
- Note that SPM values tend to always exceed the NAAQS
- However, $\text{SO}_2$ and $\text{NO}_x$ values tend to stay below NAAQS
Health and Mortality risks

• High worker, population and children densities in the central wards and in West Delhi

• High mortality and health risks occur in the North (Modeltown, etc) and East Delhi (Gautampuri, etc) due to high concentration of SPM in these locations

• Low SPM related risks in South Delhi
Worker density (Census 1991)

Worker mortality
(based on Oct 2000 air quality data)
Adult Restricted Activity days
October 2000

Adults with respiratory symptoms
October 2000
Density of children below age 6
Source: 1991 Census

Monthly mortality for children
October 2000
Density of population
Source: 1991 Census

Asthma attacks in population
October 2000
Adult exposure effects to PM10 by location in New Delhi

<table>
<thead>
<tr>
<th>LOCATION</th>
<th>Adult mortality</th>
<th>Adult RAS</th>
<th>Adult RS</th>
<th>Adults</th>
</tr>
</thead>
<tbody>
<tr>
<td>Central</td>
<td>209</td>
<td>723,368</td>
<td>2,302,196</td>
<td>413,229</td>
</tr>
<tr>
<td>North</td>
<td>220</td>
<td>761,515</td>
<td>2,423,605</td>
<td>392,350</td>
</tr>
<tr>
<td>West</td>
<td>161</td>
<td>558,666</td>
<td>1,778,016</td>
<td>499,460</td>
</tr>
<tr>
<td>East</td>
<td>132</td>
<td>456,717</td>
<td>1,453,552</td>
<td>565,068</td>
</tr>
<tr>
<td>South</td>
<td>181</td>
<td>626,278</td>
<td>1,993,197</td>
<td>461,034</td>
</tr>
</tbody>
</table>
Population exposure effects to PM10 by location in New Delhi

<table>
<thead>
<tr>
<th>LOCATION</th>
<th>Population Mortality</th>
<th>Population ERV</th>
<th>Population Asthmatic</th>
<th>Population</th>
</tr>
</thead>
<tbody>
<tr>
<td>Central</td>
<td>654</td>
<td>9,255</td>
<td>155,953</td>
<td>1,290,955</td>
</tr>
<tr>
<td>North</td>
<td>681</td>
<td>9,647</td>
<td>162,563</td>
<td>1,225,496</td>
</tr>
<tr>
<td>West</td>
<td>476</td>
<td>6,735</td>
<td>113,495</td>
<td>1,474,126</td>
</tr>
<tr>
<td>East</td>
<td>381</td>
<td>5,395</td>
<td>90,905</td>
<td>1,637,494</td>
</tr>
</tbody>
</table>
Childrens’ exposure effects to PM10 by location in New Delhi

<table>
<thead>
<tr>
<th>LOCATION</th>
<th>Child Mortality</th>
<th>Children LRI</th>
<th>Children</th>
</tr>
</thead>
<tbody>
<tr>
<td>Central</td>
<td>97.56</td>
<td>9988.54</td>
<td>193025</td>
</tr>
<tr>
<td>North</td>
<td>114.27</td>
<td>11701.97</td>
<td>207110</td>
</tr>
<tr>
<td>West</td>
<td>71.6</td>
<td>7331.54</td>
<td>220810</td>
</tr>
<tr>
<td>East</td>
<td>55.67</td>
<td>5702.45</td>
<td>251104</td>
</tr>
<tr>
<td>South</td>
<td>112.72</td>
<td>11543.01</td>
<td>283148</td>
</tr>
</tbody>
</table>
Transportation planning - New Delhi

• Who is responsible for transportation planning?
  – DDA
  – Traffic Police
  – DTC
  – TCPO

• The need for data in the context of traffic management
  – Origin Destination survey
  – Bus route studies to study high density routes
  – Trip generation models to study location of work and non work trips
  – Viability of light or heavy rail in high density locations
Delhi’s Vehicle Fleet

- Delhi has the highest road length in India: 1284km/100km² area (26,379km of total length in 1998/99)
- Car ownership (1995): 52 vehicles/1000 people

• 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.
• Delhi’s roads, if good traffic management is applied, can accommodate 2-3 times the existing number of vehicles.
• Source: Indian Institute of Technology, May 1997
Congestion & Traffic Accidents in Delhi

<table>
<thead>
<tr>
<th></th>
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<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>road length (km)</td>
<td>8,380</td>
<td>14,320</td>
<td>21,670</td>
<td>25,949</td>
<td>26,379</td>
<td></td>
<td></td>
</tr>
<tr>
<td># of vehicles (millions)</td>
<td>0.214</td>
<td></td>
<td></td>
<td>2.848</td>
<td>3.21</td>
<td>3.924</td>
<td>6</td>
</tr>
</tbody>
</table>

- Average speeds go down from 31km/hr in 1995 to 21.2km/hr in 2000.
- Road length increased by 3 times from 1972 to 1997 in Delhi while # of vehicles increased by 13 times!
- TERI 1996: Delhi is the most congested city in India.
- Average speeds during peak hour range from 10 to 15 km/hr in central areas and from 25-40 km/hr in arterial streets.
- Delhi’s traffic fatalities in 1993 were more than double those of all other major Indian cities combined.
- The # of accidents in 1995 were 10,138 which ended up with 2,074 deaths.

**Current (2000) Road Accidents in Delhi:**
Average No. of Persons Killed / Day - 5
Average No. of persons injured - 13
Buses contribute to the majority of the accidents

Source: http://www.delhimetrorail.com
• On average a car in India weighs 800kg!
• On average cars in Delhi emit the following amounts of gases in 1 year:

<table>
<thead>
<tr>
<th></th>
<th>CO</th>
<th>NOx</th>
<th>SO2</th>
<th>HC</th>
</tr>
</thead>
<tbody>
<tr>
<td>1999</td>
<td>160.2</td>
<td>16.26</td>
<td>0.4928</td>
<td>28.88</td>
</tr>
<tr>
<td>kg/car/year</td>
<td>20.03%</td>
<td>2.03%</td>
<td>0.06%</td>
<td>3.61%</td>
</tr>
<tr>
<td></td>
<td>Pb</td>
<td>TSP</td>
<td>PM10</td>
<td>CO2</td>
</tr>
<tr>
<td>1999</td>
<td>0.1971</td>
<td>1.577</td>
<td>1.281</td>
<td>3932</td>
</tr>
<tr>
<td>kg/car/year</td>
<td>0.02%</td>
<td>0.20%</td>
<td>0.16%</td>
<td>491.52%</td>
</tr>
</tbody>
</table>
Historical Vehicle Growth: Delhi

Vehicle Growth: Delhi
Vehicular Air Pollution Information System, Delhi (3)
Total Emissions from Vehicles in Delhi from 1995 to 2025

VKT, No. of Vehicles, and Emissions Trend

Index: 1995 = 1
Population, number of vehicles and speeds

<table>
<thead>
<tr>
<th>Year</th>
<th>Population (in millions)</th>
<th>Speed (km/hr)</th>
<th>No. of Vehicles</th>
</tr>
</thead>
<tbody>
<tr>
<td>1995</td>
<td>2,000,000</td>
<td>35</td>
<td></td>
</tr>
<tr>
<td>1997</td>
<td>4,000,000</td>
<td>30</td>
<td></td>
</tr>
<tr>
<td>1999</td>
<td>6,000,000</td>
<td>25</td>
<td></td>
</tr>
<tr>
<td>2001</td>
<td>8,000,000</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>2003</td>
<td>10,000,000</td>
<td>15</td>
<td></td>
</tr>
<tr>
<td>2005</td>
<td>12,000,000</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>2007</td>
<td>14,000,000</td>
<td>5</td>
<td></td>
</tr>
</tbody>
</table>

The graph shows the trend of population, speed, and number of vehicles over the years from 1995 to 2019.
# Value of Time, Fuel Costs, & Health Costs from Passenger Transport in Delhi

<table>
<thead>
<tr>
<th></th>
<th>1995</th>
<th>2000</th>
<th>2020</th>
</tr>
</thead>
<tbody>
<tr>
<td>Value of Time (million $)</td>
<td>142.34</td>
<td>314.88</td>
<td>13,939.38</td>
</tr>
<tr>
<td>Fuel Costs (million $)</td>
<td>662.36</td>
<td>1000.10</td>
<td>13,123.32</td>
</tr>
<tr>
<td>Health Costs (million $)</td>
<td>507.78</td>
<td>798.08</td>
<td>2,657.63</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>million tons of carbon per year</th>
<th>1995</th>
<th>2000</th>
<th>2020</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2.38</td>
<td>3.04</td>
<td>15.14</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th># of premature deaths per year due to air pollution</th>
<th>1995</th>
<th>2000</th>
<th>2020</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>5,863</td>
<td>6,883</td>
<td>8,607</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Traffic accidents / deaths</th>
<th>1995</th>
<th>2000</th>
<th>2020</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>10,178/2,074</td>
<td>/1,956</td>
<td>na</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>million $</th>
<th>2020</th>
<th>2020 with 2000's speed</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Value of Time</td>
<td>7,810.24</td>
<td>4,269.33</td>
<td>3,540.91</td>
</tr>
<tr>
<td>Fuel Costs</td>
<td>10,783.42</td>
<td>8,094.67</td>
<td>2,688.75</td>
</tr>
<tr>
<td>Health Costs</td>
<td>9,664.11</td>
<td>6,175.15</td>
<td>3,488.96</td>
</tr>
<tr>
<td>Total</td>
<td>28,257.77</td>
<td>18,539.15</td>
<td>9,718.62</td>
</tr>
</tbody>
</table>
Beijing

- 5 ring roads
- new housing under construction around the 5th ring road area
- 14 satellite cities being built in the suburban and rural areas
- This suburbanization and decentralization plan of Beijing will increase future pass-km demand and put more strain on the transportation system.
- 2000 population: 12,511,000
Beijing, China

- 1 meter resolution black-and-white image of the Forbidden City, Beijing.
- IKONOS satellite collected the image on October 20, 1999.
Vehicle Growth in Beijing

Historical Vehicle Growth in Beijing

Vehicle Growth in Beijing

- MCs
- Taxis
- Buses
- HDDV
- HDGV
- LDV
- Cars
UNREGULATED

NOx Emissions from Vehicles in Beijing

REGULATED

NOx Emissions from Vehicles in Beijing
UNREGULATED

CO Concentration in Beijing City

REGULATED

CO Concentration in Beijing City

NOx Concentration in Beijing City

NOx Concentration in Beijing City
## Value of Time, Fuel Costs, & Health Costs from Passenger Transport in Beijing

<table>
<thead>
<tr>
<th></th>
<th>1995</th>
<th>2000</th>
<th>2020</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Value of Time</strong></td>
<td>182.33</td>
<td>743.63</td>
<td>19,514.94</td>
</tr>
<tr>
<td><strong>Fuel Costs</strong></td>
<td>641.00</td>
<td>1,569.22</td>
<td>19,509.85</td>
</tr>
<tr>
<td><strong>Health Costs</strong></td>
<td>975.18</td>
<td>1,898.65</td>
<td>15,117.62</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>1995</th>
<th>2000</th>
<th>2020</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>million tons of carbon per year</strong></td>
<td>3.40</td>
<td>6.02</td>
<td>19.47</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>1995</th>
<th>2000</th>
<th>2020</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong># of premature deaths per year due to air pollution</strong></td>
<td>10,405</td>
<td>15,267</td>
<td>46,123</td>
</tr>
</tbody>
</table>
Value of Time, Fuel Costs, & Health Costs from Passenger Transport in 2020 Under Different Scenarios for Beijing

<table>
<thead>
<tr>
<th></th>
<th>At 6 km/hr (2020)</th>
<th>At 16km/hr (2020)</th>
<th>With Tokyo's pass-trip mix (2020)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Value of Time</td>
<td>19,514.94</td>
<td>9,348.51</td>
<td>8,631.77</td>
</tr>
<tr>
<td>Fuel Cost</td>
<td>19,509.85</td>
<td>15,281.42</td>
<td>17,879.25</td>
</tr>
<tr>
<td>Health Costs</td>
<td>15,117.62</td>
<td>11,794.00</td>
<td>8,635.45</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>54,142.41</td>
<td>36,423.93</td>
<td>35,146.47</td>
</tr>
</tbody>
</table>
Comparison of Delhi and Beijing
Beijing’s and Delhi’s Population, Vehicle Fleet, and Their Projections for 2020

<table>
<thead>
<tr>
<th>Delhi, June 1997</th>
<th># of Vehicles</th>
<th>% Modal Share</th>
<th>Beijing, 1997</th>
<th># of Vehicles</th>
<th>% Modal Share</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cars/Jeeps/Station Wagons</td>
<td>720,921</td>
<td>25%</td>
<td>Cars</td>
<td>178,566</td>
<td>16%</td>
</tr>
<tr>
<td>MC/SC/MPD</td>
<td>1,906,232</td>
<td>66%</td>
<td>MC</td>
<td>289,231</td>
<td>26%</td>
</tr>
<tr>
<td>Taxis</td>
<td>15,362</td>
<td>1%</td>
<td>Taxis</td>
<td>58,976</td>
<td>5%</td>
</tr>
<tr>
<td>Autorickshaws</td>
<td>80,210</td>
<td>3%</td>
<td>LDV</td>
<td>438,157</td>
<td>40%</td>
</tr>
<tr>
<td>Trucks</td>
<td>142,290</td>
<td>5%</td>
<td>HDGV</td>
<td>77,053</td>
<td>7%</td>
</tr>
<tr>
<td>Buses</td>
<td>39,344</td>
<td>1%</td>
<td>HDDV</td>
<td>57,088</td>
<td>5%</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Buses</td>
<td>7,269</td>
<td>1%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>1995</th>
<th>2000</th>
<th>2020</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beijing</td>
<td># of vehicles</td>
<td>858,482</td>
<td>1,669,447</td>
</tr>
<tr>
<td></td>
<td>population</td>
<td>11,705,000</td>
<td>12,511,209</td>
</tr>
<tr>
<td>Delhi</td>
<td># of vehicles</td>
<td>2,076,119</td>
<td>2,936,504</td>
</tr>
<tr>
<td></td>
<td>population</td>
<td>11,232,000</td>
<td>13,964,000</td>
</tr>
</tbody>
</table>

- 2 to 3 times more # of vehicles in Delhi.
- Similar population in 1995 and 2000 in Delhi and Beijing but higher growth for Delhi resulting in a much larger population in 2020 in Delhi (due to controlled population growth in Beijing).
### A comparison of three cities

<table>
<thead>
<tr>
<th></th>
<th>1995</th>
<th>2000</th>
<th>2020</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Delhi</td>
<td>Beijing</td>
<td>NYC SMSA</td>
</tr>
<tr>
<td><strong>Population (millions)</strong></td>
<td>11</td>
<td>12</td>
<td>18&lt;sup&gt;1&lt;/sup&gt;</td>
</tr>
<tr>
<td><strong>Vehicle Population (millions)</strong></td>
<td>2</td>
<td>1</td>
<td>8</td>
</tr>
<tr>
<td><strong>Value of Time lost (million $)</strong></td>
<td>142</td>
<td>182</td>
<td>22,253</td>
</tr>
<tr>
<td><strong>Fuel Costs (million $)</strong></td>
<td>662</td>
<td>641</td>
<td>5,464</td>
</tr>
<tr>
<td><strong>Health Costs (million $)&lt;sup&gt;3&lt;/sup&gt;</strong></td>
<td>508</td>
<td>975</td>
<td>9,238</td>
</tr>
<tr>
<td><strong>Tons of Carbon (million)</strong></td>
<td>2.4</td>
<td>3.4</td>
<td>3.0</td>
</tr>
<tr>
<td><strong>Number of premature deaths due to air pollution</strong></td>
<td>5,863</td>
<td>10,405</td>
<td>5,727</td>
</tr>
</tbody>
</table>

**Notes:**

1. 1990 US Census
2. 2000 US Census preliminary estimate
3. New York City SMSA health costs includes fixed and mobile sources
4. 1990 US Census
5. Data for NY City SMSA calculations from International Energy Agency and Census 1990
6. New Delhi has strict fuel quality and emissions requirements in future years (corresponding to EURO norms for SO₂ and PM10)
7. Beijing’s numbers are work in progress. Their fuel quality standards are not as strict as New Delhi
Applicability of Decision Support Models
GIS MODELS

• Fundamental data handling tool for urban planning.
• Link to urban air transport and diffusion models.
• Map exposure and health impacts.
• Explore air/water/land interactions
• Aid trip generation models.
Simulation Models

- Quick and easy.
- Can test assumptions about future land use and environmental regulatory policies.
- Can be integrated into GIS system.
- Ease of use for citizen involvement in planning.
MATHEMATICAL MODEL

• Include all modes of transportation
• Include different types of fuels and technologies for each mode
• Include investment opportunities in infrastructure for all transportation modes
• Include different control options
TRANSPORTATION MODES FOR DELHI

Motor Vehicles
- Cars/Jeeps/Station wagons
- 2W
- 3W-autorickshaws
- Taxis
- Buses
- Trucks

Light Rail - electric

Subway - electric

Walk

Bicycle

Tricycle
- NMV
- electric

gasoline
- diesel
- ethanol
- methanol
- natural gas
- electric
- hybrid
- LPG
- hydrogen fuel cell
Control Options To Be Considered in The Model

• Pricing Measures:
  – tax measures
  – subsidize transit services
  – subsidize clean fuels

• Incentive related and educational policy options
  – education and driver behavior
  – encourage air quality monitoring and research on health effects of pollutants
  – ride sharing
  – telecommuting

• Technical policy options
  – engine designs
  – improve fuel quality
  – catalytic converters
  – fuel switching
  – decrease scrappage rate
  – infrastructure investments
  – increase transit services

• TDM measures
  – I/M programs
  – traffic management
  – parking management
  – provide HOV and bus lanes
\textbf{MAX NET BENEFITS} = Value of Time, Health and Materials Damages - Costs from Vehicular Air Pollution

\begin{itemize}
  \item air quality standards
  \item total emission limits
  \item demand constraint (pass-km)
  \item budget constraint
  \item fuel capacity limits
  \item logical constraints
\end{itemize}

\textbf{MIN TOTAL COSTS}

\begin{itemize}
  \item air quality standards
  \item total emission limits
  \item demand constraint (pass-km)
  \item budget constraint
  \item fuel capacity limits
  \item logical constraints
  \item Accounting on Value of Time, Health and Materials Damages
\end{itemize}

Look at results of $, Health, Time, and Other Damages.

Agree on Policy

Change Constraints
Some Conclusions
STRATEGY:

Move people not vehicles!

For a more efficient transportation system:

* use low energy use per passenger-km modes
* use low emissions per passenger-km modes
* use modes with low road space consumption per passenger

Public transportation (buses, subway, light rail) achieves best values of above parameters. Therefore, their development is essential for attaining a sustainable transportation system in the future.
1. Clean fuels, clean vehicle technologies (electronic fuel injection, catalytic converters), new vehicle emission standards

2. Infrastructure investments - build new roads to add more capacity

3. Traffic and demand management (manage existing street space to maximize available capacity and implement vehicle use controls)

4. I/M programs

5. Improve public transit

6. Land-use planning

Effect on:
- speeds
- emission factors
- fuel efficiencies
- traffic flow
- driver behavior

1. Reduction of emissions per vehicle kilometers traveled
2. Reduction of the total number of vehicle kilometers traveled

- New capacity attracts new demand and so traffic congestion will continue as long as incomes, population, and vehicle ownership continue to grow.
- So while managing road space, also implement vehicle use controls (rather than vehicle ownership controls) and develop public transit!
Pollution Control Options for The Transportation Sector

- Technology options (such as new vehicle emission standards, fuel reformulation, alternative fuels) alone are not enough - standards will still be exceeded
- Infrastructure investments (build roads and develop infrastructure to sustain the growth in transportation) - road area in Beijing is 6.1% and in Delhi is 23%, whereas in other developed cities goes up to 30%
- Traffic management options to reduce congestion and increase speeds (a set of transportation system improvements such as arranging the traffic flow direction, and installation and better coordination of traffic signals)
- Employer based controls such as giving transit passes, arranging telecommuting programs, providing ride-matching information and services, and modified work schedules
- Enhanced I/M and accelerated vehicle retirement programs
- Improve public transit as a good alternative for the commuters and also by options such as parking management and road fees discourage extensive use of cars
- Environmental education and awareness programs
- Land use management
And now a word from our sponsors....
India Inc

Ford, Harvard join hands to clean up Delhi

Sandep N Hatthaboli

FORD India has teamed up with Harvard University to initiate a study on solving the bulging problem of traffic congestion and pollution in Delhi. The objective of the exercise is to prepare models that will be given to relevant organisations concerned with traffic management. The recommendations could then be implemented on a case-to-case basis. A workshop on awareness of the study will be held in April.

Foul air

In an exclusive meeting with Auto Monitor two key members - Peter Rogers of Harvard University and Wei-juan Han of Ford Asia Pacific - said that quality of air in India was getting progressively worse. This was despite the government’s efforts to curb pollution through imposition of stringent emission norms. The biggest hurdle has been the age of the existing fleet coupled with the growing number of vehicles entering the market.

"Though we have new cars fitted with better technology, the solution lies in reducing the ageing fleet, increasing speeds and decreasing congestion," said Rogers, who is professor of environmental engineering and city planning at Harvard University.

The result of little coordination between government agencies on traffic, infrastructure and land management. Wei-juan Han, R&D programs manager of Ford Asia Pacific, said that the study would create awareness among the various institutions and non-government organisations (NGOs) which will implement the model.

The study will be based on a set of intersecting models that will relate to database and geographic information. These will project the impact of any CD-ROM model by end-2001. The suggestions will then be implemented in various regions of Delhi.

Initial impact study

The study has roped in organisations like the Pune-based Central Institute of Road Transport (CIRT) which will implement similar models in other congested metros such as Mumbai, Hyderabad and Bangalore. The initial impact study will be out by 2003.

Ford and Harvard are and mortality cases registered. Rogers said that the model would indicate which class of people will be the worst affected by air quality.

The duo said that a similar project is being carried out in Beijing, China. According to them, on a direct comparison basis, though the average area is the same for both cities, Delhi still scores. This is because roads take up 30 percent of its land. However, Beijing observes greater traffic discipline with separate lanes/roads for two...