Integrated Analysis of Transportation Development and Air Quality Strategy in China

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Outline

• Overview of urbanization
• Overview of motorization
• Air pollution from urban transportation
• Beijing Case
• Future Consideration
Outline

- Overview of urbanization
- Overview of motorization
- Air pollution from urban transportation
- Beijing Case
- Future Consideration
Overview of urbanization

• Increase of number for Chinese cities
Overview of urbanization

- Development of Chinese population and urbanization
Urbanization Trends in China

Urban Population (10,000)

- > 200
- 100-200
- 50-100
- 20-50
- <20

1994
1998
Outline

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Overview of motorization

Vehicle Stocks in Thousand

- Passenger Vehicles
- Trucks
- Total Vehicles

<table>
<thead>
<tr>
<th>Year</th>
<th>Passenger Vehicles</th>
<th>Trucks</th>
<th>Total Vehicles</th>
</tr>
</thead>
<tbody>
<tr>
<td>1990</td>
<td>1000</td>
<td>1500</td>
<td>2500</td>
</tr>
<tr>
<td>1991</td>
<td>1100</td>
<td>1600</td>
<td>2700</td>
</tr>
<tr>
<td>1992</td>
<td>1200</td>
<td>1700</td>
<td>2900</td>
</tr>
<tr>
<td>1993</td>
<td>1300</td>
<td>1800</td>
<td>3100</td>
</tr>
<tr>
<td>1994</td>
<td>1400</td>
<td>1900</td>
<td>3300</td>
</tr>
<tr>
<td>1995</td>
<td>1500</td>
<td>2000</td>
<td>3500</td>
</tr>
<tr>
<td>1996</td>
<td>1600</td>
<td>2100</td>
<td>3700</td>
</tr>
<tr>
<td>1997</td>
<td>1700</td>
<td>2200</td>
<td>3900</td>
</tr>
<tr>
<td>1998</td>
<td>1800</td>
<td>2300</td>
<td>4100</td>
</tr>
<tr>
<td>1999</td>
<td>1900</td>
<td>2400</td>
<td>4300</td>
</tr>
<tr>
<td>2000</td>
<td>2000</td>
<td>2500</td>
<td>4500</td>
</tr>
</tbody>
</table>
Stock of civil autos by ownership, 1985~1997

Private-owned auto stock
Non-private auto stock
Share of private-owned vehicle stock by purpose (1985~1997)
Overview of motorization

• Growth of total civil motor vehicle population in Beijing

![Bar chart showing the growth of total civil motor vehicle population in Beijing from 1990 to 1999.](chart.png)
Overview of motorization

• Growth of total civil motor vehicle population in Shanghai
Overview of motorization

• Growth of total civil motor vehicle population in Guangzhou
Number of Motor Vehicles

- Tokyo Total
- Tokyo Passenger cars
- Tokyo Buses and Trucks
- Tokyo (ward area) Total
- Tokyo (ward area) Passenger cars
- Tokyo (ward area) Buses and Trucks
- Seoul Total
- Seoul Passenger cars
- Seoul Buses and Trucks
- Beijing Total
- Beijing Passenger cars and buses
- Beijing Trucks

Number of motor vehicles (thousands)

- 0
- 500
- 1,000
- 1,500
- 2,000
- 2,500
- 3,000
- 3,500
- 4,000
- 4,500

Year:
- 1900
- 1910
- 1920
- 1930
- 1940
- 1950
- 1960
- 1970
- 1980
- 1990
- 2000
Number of Passenger Cars

- Tokyo Passenger cars
- Seoul Passenger cars
- Beijing Passenger cars and buses

Number of motor vehicles (thousands)

- 0
- 500
- 1,000
- 1,500
- 2,000
- 2,500
- 3,000
- 3,500
- 4,000

Number of Trucks and Buses

- Tokyo Buses and Trucks
- Seoul Buses and Trucks
- Beijing Trucks
Motorization
(Vehicles per 1000 people)

- Japan
- Tokyo
- Tokyo Ward area
- Korea
- Seoul
- China
- Beijing

Vehicles per 1000 people
Road Provision per Registered Vehicle
(length of paved road/vehicle)
Passenger Traffic by Public Transportation Mode in Tokyo

- Tokyo (ward area) Taxi
- Tokyo (ward area) Buses
- Tokyo (ward area) Subway
- Tokyo (ward area) Tram/Train
Passenger Traffic by Public Transportation Mode in Beijing

Annual passenger traffic (1,000 passenegers)

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NOx Concentration for Different Scale Cities

NOx concentration (mg/m³)

- > 200
- 100-200
- 50-100
- 20-50
- <20

Comparison between 1994 and 1998
Rates of NOx exceeding standard

<table>
<thead>
<tr>
<th>城市人口（万人）</th>
<th>1994</th>
<th>1998</th>
</tr>
</thead>
<tbody>
<tr>
<td>＞200</td>
<td>80%</td>
<td>60%</td>
</tr>
<tr>
<td>100-200</td>
<td>40%</td>
<td>20%</td>
</tr>
<tr>
<td>50-100</td>
<td>20%</td>
<td></td>
</tr>
<tr>
<td>20-50</td>
<td></td>
<td></td>
</tr>
<tr>
<td>＜20</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### NOx Concentration in Chinese cities

<table>
<thead>
<tr>
<th>year</th>
<th>No. Of cities</th>
<th>Non-attainment cities</th>
<th>Non-attainment for Class II standard</th>
<th>Non-attainment for Class III standard</th>
<th>Non-attainment cities for Class III</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>number</td>
<td>rate (%)</td>
<td>number</td>
<td>rate (%)</td>
</tr>
<tr>
<td>1995</td>
<td>88</td>
<td>32</td>
<td>36.4</td>
<td>3</td>
<td>3.4</td>
</tr>
<tr>
<td>1996</td>
<td>88</td>
<td>27</td>
<td>30.7</td>
<td>25</td>
<td>28.4</td>
</tr>
<tr>
<td>1997</td>
<td>94</td>
<td>32</td>
<td>34.1</td>
<td>29</td>
<td>30.9</td>
</tr>
<tr>
<td>1998</td>
<td>96</td>
<td>32</td>
<td>33.3</td>
<td>29</td>
<td>30.2</td>
</tr>
</tbody>
</table>
Beijing: Air Pollutant Concentrations

Air Quality in Beijing from 1997-1999 (mg/m³)

<table>
<thead>
<tr>
<th>year</th>
<th>SO2</th>
<th>NOx</th>
<th>CO</th>
<th>TSP</th>
</tr>
</thead>
<tbody>
<tr>
<td>1997</td>
<td>0.125</td>
<td>0.133</td>
<td>3.0</td>
<td>0.318</td>
</tr>
<tr>
<td>1998</td>
<td>0.120</td>
<td>0.152</td>
<td>3.3</td>
<td>0.378</td>
</tr>
<tr>
<td>1999</td>
<td>0.080</td>
<td>0.140</td>
<td>2.9</td>
<td>0.364</td>
</tr>
</tbody>
</table>
BEIJING: NOx Concentration In 1998

Monthly NOx concentration distribution in 1998

2# and 3# monitoring stations are near to the arteries, and 6# monitoring station is far away from the arteries.
## Ozone concentration in Beijing

<table>
<thead>
<tr>
<th>Year</th>
<th>Number of non-attainment days</th>
<th>Number of non-attainment hours</th>
<th>Max. Hourly concentration (µg/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1997</td>
<td>71</td>
<td>434</td>
<td>346</td>
</tr>
<tr>
<td>1998</td>
<td>101</td>
<td>504</td>
<td>384</td>
</tr>
<tr>
<td>1999</td>
<td>119</td>
<td>777</td>
<td></td>
</tr>
</tbody>
</table>
Beijing: #PM_{2.5} Mass Concentration Levels in 1999-2000

- Similar temporal variations at the two sites
- Strong weekly variations: *max difference for two consecutive weeks is 2.5 times*
Shanghai: NOx and SO2 Concentrations from 1990 to 1999
Shanghai: CO Concentration

Concentration, mg/m³

图 1 PM2.5 周平均浓度的变化曲线
Fig. 1 Weekly PM2.5 variations at two sampling sites

图 1 PM2.5 周平均浓度的变化曲线
Fig. 1 Weekly PM2.5 variations at two sampling sites

Conc. (μg/m³)

Week

03/20~03/27
04/17~04/24
05/17~05/24
06/14~06/21
07/12~07/19
08/09~08/16
09/06~09/13
10/04~10/11
11/02~11/09
11/30~12/07
12/28~01/03
01/24~01/31
02/21~02/28
03/20~03/27

Tongji Univ.

70 Hainan Rd.
### Guangzhou: Air Quality from 1997-1999 (mg/m³)

<table>
<thead>
<tr>
<th>Year</th>
<th>SO₂</th>
<th>NOₓ</th>
<th>CO</th>
<th>TSP</th>
</tr>
</thead>
<tbody>
<tr>
<td>1997</td>
<td>0.07</td>
<td>0.139</td>
<td>2.54</td>
<td>0.217</td>
</tr>
<tr>
<td>1998</td>
<td>0.061</td>
<td>0.124</td>
<td>2.42</td>
<td>0.202</td>
</tr>
<tr>
<td>1999</td>
<td>0.054</td>
<td>0.114</td>
<td>2.29</td>
<td>0.182</td>
</tr>
</tbody>
</table>
Air Pollutant Concentration in Three Cities

**TSP**

- Yearly average concentration in Beijing, Guangzhou, and Shanghai.

**NOx**

- Yearly average concentration in Beijing, Guangzhou, and Shanghai.

**CO**

- Yearly average concentration in Beijing and Guangzhou.
Outline

• Overview of urbanization
• Overview of motorization
• Air pollution from urban transportation
• Beijing Case
• Future Consideration
Methodology: Model Description

- Model Description
  - Diffusion model
  - Emission distribution
  - Emission factor model
  - Transfer matrix
  - Optimization model for control measure options

Energy & Traffic
- Vehicle information
- Energy & traffic
- Ave. speed
- Cold/heat start
- Drive cycle
- Fuel

Population
- Population
- Population
- Registration
- Mileage
- I/M

Strategies and policy
- Control targets
- Strategies and policy
Methodology: Grid system

grid system is needed (364, 1.5km*1.5km grids)

In Beijing, the road system can be described briefly as a network, with ring roads (thick solid lines) and radial roads (fine red lines) as its arteries.
Calculation of Vehicle Emission Factors

- Modified Mobile5 model was used to calculate emission factors
  - Modification items
    - RVP
    - Temperature
    - Driving cycle conditions
    - Speed
    - I/M
    - Other factors (air conditioning used, overloaded and so on)

\[ EF = FUN (CMFALUH) \]
MOBILE SOURCE CONTRIBUTION TO AIR POLLUTANT CONCENTRATIONS

Hourly traffic flow variation
Three cases in Beijing

- Formulating mobile source control strategy from 1995 to 2010
- Evaluating the effectiveness of air pollution control measures since 1998
- Prediction of air quality in 2008
Case I: Mobile Source Emission Inventory (NOx, 1995, t/y)
Case I: MOBILE SOURCE CONTRIBUTION TO AIR POLLUTANT CONCENTRATIONS

- Spatial distribution of annual average concentrations in 1995

**CO**

**NOx**
## Case I: MOBILE SOURCE CONTRIBUTION TO AIR POLLUTANT CONCENTRATIONS

<table>
<thead>
<tr>
<th>Year</th>
<th>Emissions,(t))</th>
<th>Pollution Share for Emission (%)</th>
<th>Pollution Share for Concentration (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Urban Area</td>
</tr>
<tr>
<td>CO</td>
<td>1995 年</td>
<td>107.5</td>
<td>76.8</td>
</tr>
<tr>
<td></td>
<td>1998 年</td>
<td>129.0</td>
<td>82.7</td>
</tr>
<tr>
<td>NOx</td>
<td>1995 年</td>
<td>9.38</td>
<td>40.2</td>
</tr>
<tr>
<td></td>
<td>1998 年</td>
<td>11.5</td>
<td>42.9</td>
</tr>
</tbody>
</table>
### Case I: Scenarios for control option

#### Mobile source control strategies (Scenario 2)

--- For new vehicles

<table>
<thead>
<tr>
<th></th>
<th>EURO 1</th>
<th>EURO 2</th>
<th>EURO 3</th>
<th>EURO 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Motorcycles</td>
<td>2001.1</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Case I: IMPACTS OF EMISSION CONTROL ON AIR QUALITY

- The reduction potential of different control strategies

![Graphs showing emission reductions over time for CO and NOx pollutants.](image-url)
Case I: IMPACTS OF EMISSION CONTROL ON AIR QUALITY

CO concentration with control (ug/m^3)

2002

2010
Case I: Government Action

☆ Beijing: emission standard for exhaust pollutants from light-duty vehicles

☆ Shanghai: emission standard for exhaust pollutants from light-duty vehicles

☆ Emission Standard for exhaust pollutants from light-duty vehicles （GWPB1-1999）

☆ Standard for hazardous contents in gasoline （GWPB001-1999）
<table>
<thead>
<tr>
<th>Vehicle type</th>
<th>vehicle no.</th>
<th>NOx red.</th>
<th>Ratio to popu.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scrap m-bus</td>
<td>14000</td>
<td>8902</td>
<td>6.3%</td>
</tr>
<tr>
<td>Scrap other</td>
<td>24000</td>
<td>4648</td>
<td>3.3%</td>
</tr>
<tr>
<td>Temp. stop</td>
<td>3782</td>
<td>732</td>
<td>0.5%</td>
</tr>
<tr>
<td>return</td>
<td>544/day</td>
<td>211</td>
<td>0.1%</td>
</tr>
<tr>
<td>retrofit</td>
<td>56416</td>
<td>4696</td>
<td>3.3%</td>
</tr>
</tbody>
</table>
### Case II:
**Measures for mobile source in phase II**

<table>
<thead>
<tr>
<th>Vehicle type</th>
<th>vehicle no.</th>
<th>NOx red.</th>
<th>Ratio to popu.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scrap m-bus</td>
<td>6762</td>
<td>4300</td>
<td>3.05%</td>
</tr>
<tr>
<td>Scrap other</td>
<td>13238</td>
<td>2564</td>
<td>1.82%</td>
</tr>
<tr>
<td>Temp. stop</td>
<td>17000</td>
<td>3292</td>
<td>2.33%</td>
</tr>
<tr>
<td>return</td>
<td>370</td>
<td>143</td>
<td>0.10%</td>
</tr>
<tr>
<td>retrofit</td>
<td>312500</td>
<td>15130</td>
<td>10.73%</td>
</tr>
<tr>
<td>PCV</td>
<td>62000</td>
<td>8405</td>
<td>5.96%</td>
</tr>
</tbody>
</table>
**Case II:**
Measures for mobile source in phase III

<table>
<thead>
<tr>
<th>Vehicle type</th>
<th>vehicle no.</th>
<th>NOx red.</th>
<th>Ratio to popu.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temp. stop</td>
<td>430 / week</td>
<td>1082.582</td>
<td>0.77%</td>
</tr>
<tr>
<td>return</td>
<td>94 / day</td>
<td>36.41</td>
<td>0.03%</td>
</tr>
<tr>
<td>retrofit</td>
<td>12000</td>
<td>998.78</td>
<td>0.71%</td>
</tr>
</tbody>
</table>
Case II: Measures for mobile source in phase IV

☆ Attainment rate for vehicle emission control reached 90%, which results in 8922.4 ton NOx reduction

☆ Measures for stationary sources is considered in the calculation
**Effectiveness from four phases’ control measures**

- **emission reduction**  
  (baseline: 1998)

<table>
<thead>
<tr>
<th></th>
<th>SO₂</th>
<th>NOx transport</th>
<th>NOx coal</th>
<th>PM10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phase 1</td>
<td>1.31%</td>
<td>4.52%</td>
<td>0.27%</td>
<td>0.4%</td>
</tr>
<tr>
<td>Phase 2</td>
<td>11.02%</td>
<td>9.68%</td>
<td>2.86%</td>
<td>3.9%</td>
</tr>
<tr>
<td>Phase 3</td>
<td>23.39%</td>
<td>12.84%</td>
<td>4.77%</td>
<td>8.8%</td>
</tr>
<tr>
<td>Phase 4</td>
<td>27.63%</td>
<td>15.53%</td>
<td>6.84%</td>
<td>11.4%</td>
</tr>
</tbody>
</table>
Effectiveness from four phases’ control measures

Air concentration reduction (model calculation)
(baseline: 1998)

<table>
<thead>
<tr>
<th></th>
<th>SO₂ (μg/m³)</th>
<th>NOx (μg/m³)</th>
<th>PM10 (μg/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>After control</td>
<td>76.4</td>
<td>123.6</td>
<td>174.2</td>
</tr>
<tr>
<td>Reduction rate</td>
<td>35.8%</td>
<td>16.5%</td>
<td>5.3%</td>
</tr>
</tbody>
</table>
Effectiveness from four phases’ control measures

四期措施后相对于1998年的削减率
Case III: Prediction of PM10 Concentration in Beijing in 2008
Case III: Prediction of NOx Concentration in Beijing in 2008

Mobile source control strategies (Scenario 2)

- For new vehicles
  - EURO 1
  - EURO 2
  - EURO 3
  - EURO 4
- Light-duty vehicles
- High-duty vehicles
- Motorcycles
  - 2001.1.1
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Future plan for Beijing’s Railroad
**Clean transportation for Olympics**

<table>
<thead>
<tr>
<th>Mode</th>
<th>1999</th>
<th>2007</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subway</td>
<td>1.3 million person-trip / day</td>
<td>2.5 million person-trip / day</td>
</tr>
<tr>
<td>Mass Transit</td>
<td>9 million person-trip / day</td>
<td>18 million person-trip / day</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>34,000 clean fuel vehicle, 1300 pure CNG</td>
<td></td>
</tr>
<tr>
<td></td>
<td>8 million bicycles</td>
<td></td>
</tr>
</tbody>
</table>
ELEMENETS OF A COMPREHENSIVE VEHICLE POLLUTION CONTROL STRATEGY

CLEAN VEHICLE TECHNOLOGY

APPRIOPRIATE MAINTENANCE

TRANSPORTATION & LAND USE PLANNING

CLEAN FUELS
THANK YOU !