

**Traffic and urban air pollution,
the case of Xi'an city, P.R.China**

Mao Zhongan¹,
Sjaak Slanina², Gert Spaargaren³, Zhang Yuanhang⁴

Abstract

Xi'an city is the key economic center and transportation axis for the central and western region of China. It is better known throughout the world for its historical relics and antiquities. Xi'an suffers high-level pollution of particulate matter and its air quality has been moderately to heavily polluted since the last decade. It was listed as one of the worst polluted cities in the world for several times at the early 1990s. For the sustainable development of the city, its tourism and economy, there is great need for pollution control and environmental quality improvement.

In this article, the author made a quantitative analysis of traffic emission and its effects on the urban environment in Xi'an, and a comprehensive strategy for vehicle-based pollution control is supplemented. Based on the estimation done in this study, the share of NO_x, HC and CO pollution from urban traffic in Xi'an stands at around 46.43%, 62.47% and 51.64% at present. The study also shows that vehicle emission of NO_x will increase even if the strict vehicle emission standards are going to be adopted, the share of NO_x emission from traffic will increase to 63.38% by 2010. The introduction of new standards will reduce HC and CO emission by a large degree by 2005, but with the increase of vehicle population and kilometers driven, their emission will slightly increase after 2005.

Traffic pollution is becoming a main source of urban air pollution in Xi'an. There is an emergent need for traffic pollution control strategies. Studies on transport and emission control often take a technological focus. Improvement in vehicle technology can help reduce emissions considerably, but it will be offset by the increase of vehicle ownership and kilometers driven, as shown in this study. The other objective in most urban areas is to reduce transport demand by planning, regulatory and fiscal measures. Experiences from different countries and cities show that there is no single unambiguous and effective remedy. Because there are so many complex factors interacting in the transport sector's effect on pollution, a holistic approach is necessary, that is, a combination of all the types of policy measures.

Keywords: Traffic emission, air pollution, transport, Xi'an, China

¹ Xi'an City Planning and Design Institute, China, e-mail: maozhongan@sohu.com

² Meteorology and Air Quality Group, Wageningen University, the Netherlands, e-mail: slanina@ecm.nl

³ Environmental Policy Group, Wageningen University, the Netherlands, e-mail: Gert.spaargaren@alg.swg.wau.nl

⁴ Center for Environmental Science, Beijing University, China, e-mail: yhzhang@pku.edu.cn

1. Background

Automotive air pollution, once largely a problem of developed countries, is an alarming environmental problem in developing countries. Rapid urbanization, motorization and economic growth are contributors to an increasing air pollution problem in most large and medium sized developing urban centers. Without effective measures to curb air pollution, some 300-400 million city-dwellers in developing countries will become exposed to unhealthy and dangerous levels of air pollution in the next decade (Faiz A. 1990). As one of the developing countries with a rapidly growing economy, China, especially its large cities, is also facing a similar environmental threat. Outdated technology and industrial pollution, high population pressure, fast urbanization process and increased motorization have driven most Chinese cities suffering from urban air pollution.

The contribution from the transport sector is estimated by 30-50% of the environment pollution in Chinese cities (Huang, 1997). Recent data of some large cities show that the air pollution contributed from motor vehicles is much higher than before as shown in Table 1: Share of traffic emissions in Selected Chinese Cities. Traffic emission has become one of the most important sources of urban air pollution in Beijing, Shanghai and Guangzhou.

Studies on transport and emission control often take a technological focus. Technology improvements can be aimed at the vehicle (either fuel efficiency or emissions control) and the fuel (either cleaner hydrocarbons or alternative fuels like electricity). Moreover, a wide range of policy measures have recently been proposed to cope with the high social costs of automotive pollution in some developed countries -- for example, information campaigns, economic instruments, traffic demand management, new forms of land use and physical planning...(Peter Nijkamp, 1997). Another objective in most urban areas is to stimulate public transport and to reduce private car use. Experiences from different countries and cities have shown that there is no single unambiguous and effective remedy. Because there are so many complex factors interacting in the transport sector's effect on pollution, a holistic approach is necessary, that is, a combination of all the types of policy measures. These control strategies and policies are required to be based on a scientific understanding of the pollution characteristics. Within this framework, it is important to project the total vehicular emissions and the high pollutants concentration in the near future in order to develop sound vehicular pollution control policies.

Table 1: Share of traffic emissions in Selected Chinese Cities

	CO	HC	NOx
Beijing (2000) ^A	76.8%	78.3%	40.0%
Shanghai (1996) ^B	86.0%	96.0%	56.0%
Guangzhou (2000) ^C	83.8%	50%	45%
Shenyang (1990) ^D	27-38%		45-53%

Source: A.Hao, Fu, 2001. B.Lu Shuyu, 1998. C.Shao Min, 2000. D.He *et al.*, 1996.

Xi'an, the provincial capital of Shaanxi Province, is the key economic center and transportation axis for the central and western region of China. It is better known throughout the world for its historical relics and antiquities. Xi'an suffers high-level pollution of particulate matter and its air quality has been moderately to heavily polluted since the last decade. It was listed as one of the worst polluted cities in the world for several times at the early 1990s. With the fast economic development accompanied by increasing urbanization and motorization, traffic pollution is becoming another great potential threat for the city's ambient environment.

Air quality in Xi'an is moderately to heavily polluted comparing to other Chinese cities. According to the Chinese National Ambient Quality Standards (NAAQS), air quality in Xi'an ranked grade I for 1 day, grade II for 219 days, grade III for 144 to grade 4 for 1 day in 2000. Ambient air pollution is a big threat to the urban

environment and human health. Total suspended particulate (TSP) is the chief pollutant around the year. But with the increase of motor vehicles and kilometers driven, NOx is the other potential threat to the urban environment.

Table 2: Air quality in Xi'an from August 7 2000 to August 6 2001 (365 days)

Primary pollutant	TSP	364 days	99.7%
NAAQS Grade I	No pollution	1 day (on Oct. 11, 2000)	0.3%
NAAQS Grade II	Light pollution	219 days	60.0%
NAAQS Grade III1	Moderate pollution	133 days	36.4%
NAAQS Grade III2	Moderate pollution	11 days	3.0%
NAAQS Grade IV1	Heavy pollution	1 day	0.3%

Source: Xi'an Daily Environmental Reports, collected by the author.

2. Motor vehicle increase and traffic pollution

Private car ownership was not allowed before 1980 in China. The ratio of vehicles to population in Xi'an is still very low comparing the developed world and other coastal Chinese cities. But in recent years the number of motor vehicles increased very rapidly. From 1980 to 1998, the annual average growth of motor vehicles in Xi'an was 12.3%. Over the last five years the growth rate has been 16.8% annually. (Xi'an Subway Pre-feasibility Research Report, 2000)

Research shows that the acquisition of cars is strongly related to their cost relative to people's income and the rate of growth is related to the growth of the economy (Wootton and Pick 1996, Dot 1997). The number of cars is expected to rise to 240,000 by 2010 with individual ownership increasing to 60% of all road vehicles (Xi'an Transport Development Plan 1995-2010). With average GDP growth rate of 12.9% in the last five years and the present great opportunity of National Western-Development Priority Policy implementation, this figure is unlikely to be over-estimated.

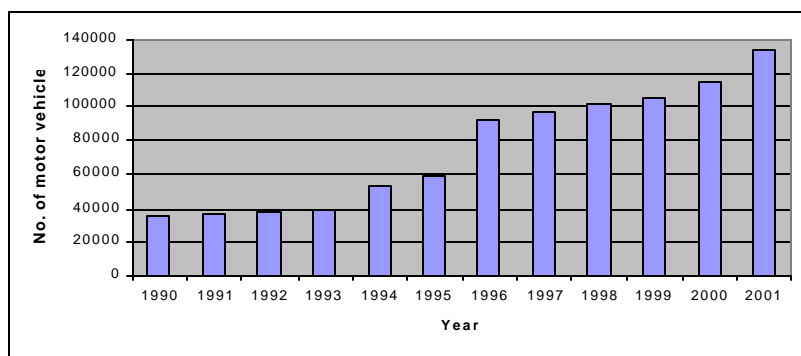


Figure 1: Number of motor vehicles in Xi'an city (Motorcycle not included)

Source: Xi'an Vehicle Registration Office, Xi'an Statistical Yearbooks

By comparing with Beijing, Shanghai and Guangzhou, the present vehicle fleet in Xi'an stands almost the same level of motorization of these three cities around the year 1990. The personal income and GDP in Xi'an are also lagged behind these three cities by 8 to 10 years. The unprecedented motor vehicle growth in these three cities in the 1990s is likely to happen in this coming decade in Xi'an. Motor vehicle pollution these three cities experienced is more likely to happen in Xi'an in the next few years if no strict control strategies adopted.

Lack of data on traffic pollution

In the city of Xi'an, there are few data available as to vehicle emission factors and traffic pollution. There is no systematic monitoring of roadside pollutants concentration. Few researches have been done on traffic pollution and its control.

In order to have a general overview of the traffic pollution at present and in the near future, the author made two case studies. One on the city scale vehicular emission in 2001, 2005 and 2010, the other on vehicle emission intensity at present and in the near future along 6 selected roads before and after being broadened in 2002.

3. Case study 1: Vehicular emission in Xi'an city in 2001, 2005 and 2010

Car model

Road traffic is responsible for an important proportion of air pollution, especially in urban areas. It is therefore necessary to quantify their emissions as accurately as possible. To estimate pollutant quantities it is necessary to have reliable emission factors and reliable activity data, in this case, traffic and mobility data.

Data collection

The vehicle population data is from the Vehicle Registration Office, the traffic flow data is from Xi'an Municipal Transport Bureau and Xi'an transport plan 1995-2010. The projected vehicle increase rate is made based on the national and municipal statistical yearbooks and Xi'an transport plan 1995-2010.

There are no emission factors available in Xi'an at present. In 1995, Tsinghua University did an emission factor project in Beijing. For the similar urban driving condition and in-use vehicle inspection standards between Beijing in 1995 and Xi'an in 2001, we directly use the emission factor of Beijing 1997 for the present Xi'an vehicle emission calculation. For the year 2005 and 2010, the emission factors are directly copied from the Netherlands urban driving condition statistics in 1992 and 1998, when the Netherlands started to adopt emission standards Euro I and Euro II.

Emission factors

Pollutant emission levels from in-service vehicles vary depending on vehicle characteristics, operating conditions, level of maintenance, fuel quality and ambient conditions such as temperature, humidity and altitude. The emission factor is defined as the estimated average emission rate for a given pollutant for a given class of vehicles. Estimates of vehicle emissions are obtained by multiplying an estimate of the distance traveled by a given class of vehicles by an appropriate factor.

Due to lack of meteorological data and the time limitation, we use only the simple car-model to make a rough estimation of the traffic emission in the city construction area of Xi'an as a whole in this section and emission intensities along 6 selected streets in section 4.

The basic formula for estimating emissions using obtained emission factors is:

$$Emission (g) = emission\ factor (g/km) * Vehicle\ kilometers\ traveled (km)$$

For a segment of an artery with the length of L, the traffic characters are assumed to be constant, the emission intensity of line sources can be calculated as follows:

$$E_p = \sum_{i=1}^n L * N_i * F_{pi}$$

L: Length of the road researched (km)

N_i: Traffic flow, number of vehicles of type i passing through the road segment (vehicle/hour)

F_{pi}: Emission factor of vehicle type i (g/km)

i: Vehicle types (1 to n)

E_p: Emission intensity of a line segment (g/hour/km)

p: the pollutant type (CO, HC or NO_x)

The emission intensity of area sources can be estimated by the following approach.

$$E_p = \sum_{i=1}^n L_i * N_i * F_{pi}$$

L_i: Average length of travel by vehicle type i (daily/yearly) in the city (km)

N_i: Number of vehicles of type i (vehicles)

i: Vehicle type (1 to n)

F_{pi}: Emission factor of vehicle type i (g/km)

E: Total vehicle emission in the city (g/day or year)

Calculation results

A semi-top-down method is used in the research since traffic flow data are not complete, and some parameters are determined subjectively. These should be verified. The most important one is the miles traveled by different types of vehicles. For verification of total mileage traveled, fuel consumption data can be used. It is estimated that the total gasoline are consumed in Xi'an by summing up the products of fuel consumption factors with the mileage traveled of each vehicle category. It is easy to notice the difference by comparing the real sales and the estimation.

City scale vehicle emission projection

Estimation of vehicle emission in Xi'an should be based on the vehicle fleet and the distances traveled by different vehicles for the planned years.

Table 3: Number of different types of Vehicles (unit: *1000)

Vehicle types	Year 2001	Year 2005	Year 2010
Passenger cars	45.7	94.8	235.9
LDGV ⁵	18.8	32.3	63.6

⁵ LDGV: light-duty gasoline vehicle

MDGV ⁶	21.6	37.1	73.0
LDDV ⁷	23.3	40.0	78.8
MDDV ⁸	19.4	33.3	65.5
HDDV ⁹	9.5	16.3	32.0
Motorcycles	94.8	64.8	34.8
Total	233.1	318.6	583.6

Sources: Xi'an Vehicle Registration Office, Xi'an statistical books.

The increase rate of passenger car is 20% year by year. This is difficult to define for the uncertainties, the private car increase rate in Beijing ranges from 16.1% to 85.6% during the period of 1985 to 1995. The motor vehicle increase rate in Xi'an was 16.4% in the last 11 years. The author believes that the passenger cars will increase faster than the total vehicle increase. For other vehicles the rate is 14.6%, the same increase rate as the national MV increase rate of the 1990s.

Table 4: Average distance traveled by different types of vehicles (Unit: *1000 km)

Vehicle types	Year 2001	Year 2005	Year 2010
Passenger cars	29.6	34.0	37.8
LDV	23.6	27.1	30.2
MDV	18.0	20.7	23.0
HDV	14.9	17.1	19.1
Motorcycles	7.3	7.3	7.3

Source: Xi'an Transport Plan 1995-2010.

Table 5: Emission factors Beijing 1995 (Unit: g/km)

Vehicle types	NOx	CO	HC
Passenger cars	2.80	41.52	8.71
LDV	1.81	66.04	6.53
MDV	4.77	77.34	13.70
HDV	27.02	22.40	5.39
Motorcycles	0.10	14.81	5.98

Source: He kenbin, 2000

Table 6: Emission factors 1992 and 1998, Urban driving in the Netherlands (g/km)

Emission factors		1992			1998		
		CO	NOx	HC	CO	NOx	HC
Cars and light-duty vehicles	Average	11.8	1.2	2.05	8.4	0.8	1.26
	Petrol	16.8	1.4	2.81	11.6	0.8	1.67
	Diesel	1.2	0.7	0.31	0.9	0.8	0.18
Medium-duty vehicles	Average	6.4	2.1	1.31	2.8	1.4	0.5
	Petrol	26.9	3.4	4.52	19.1	2.1	2.74
	Diesel	1.5	1.7	0.46	0.8	1.2	0.2
Heavy-duty vehicles	Average	5.0	12.7	3.06	2.7	10.3	1.62
	Petrol	84.9	6.5	7.39	84.9	6.5	7.39
	Diesel	4.9	12.7	3.05	2.6	10.3	1.61

Source: Central Bureau of Statistics, the Netherlands, <http://www.cbs.nl>.

⁶ MDGV: Medium-duty gasoline vehicle

⁷ LDDV: light-duty diesel vehicle

⁸ MDDV: Medium-duty diesel vehicle

⁹ HDDV: Heavy-duty diesel vehicle

Emission factors 2001 in Xi'an are based on Beijing 1995 factors, for the same emission standards and similar driving condition. The average driving speed in Beijing in 1995 was 23 km/hour and in Xi'an in 2001 is 17 km/hour. Taking into consideration of vehicle fleet ages and road conditions between the two cities, therefore the emission factor in Xi'an is reasonable.

Emission factors 2005 and 2010 adopt directly from the emission factors under urban driving condition in the Netherlands. The Netherlands adopted Euro I in 1992 and Euro II in 1998. As mentioned before China planned to adopt Euro I in 2000, and Euro II in 2005 and Euro III in 2010. Because compliance with new emission standards according to the schedule seems always several years later than the planned schedule, and the possibility of catching up with the European standards in 10 years seems not practical. In this thesis the author makes the calculations of traffic pollution by assumption that by year 2005 all vehicles meet Euro I and by 2010 all vehicles meet Euro II, therefore the emission factors of the Netherlands can be used directly for this pollution estimation.

Comparing between Xi'an and the Netherlands urban driving emission factors, the present emission factors in Xi'an is at the stage of the Netherlands in early 1970s. Can Xi'an catch up with the Netherlands emission reduction in just 10 years for the achievement the Netherlands made for more than 20 years? Therefore, the calculation for year 2005 and 2010 is really optimistic.

Table 7: Vehicle emission in Xi'an(×1000 ton)

	NOx	CO	HC
2001	13.00	192.23	33.28
2005	20.39	77.82	17.23
2010	25.96	130.72	22.12

Table 8: Contribution of vehicular pollution in 2001 (Unit: *1000 ton)

	NOx	CO	HC
Mobile sources/%	13.00/46.43%	192.23/51.64%	33.28/62.47%
Stationary sources/%	15/53.57%	180/48.36%	20/37.53%
Total	28/100%	372.23/100%	53.28/100%

Table 9: Comparison of vehicle fleet and emission between Beijing and Xi'an

	Beijing in 1995	Xi'an in 2001
Vehicle fleet	859,000	233,000
Average speed	23 km/hour	17km/hour
Vehicle emission: CO	1075.1*10 ³ ton/76.8%	192.23*10 ³ ton/51.64%
Vehicle emission: NOx	93.4*10 ³ ton/40%	13.00*10 ³ ton/46.43%
Vehicle emission: HC	174.49*10 ³ ton/78.3%	33.28*10 ³ ton/62.47%

Result analysis

Comparing with the vehicle fleet and emissions in Beijing 1995, the traffic emission projection result is good. In Beijing and Guangzhou, the three pollutants emission of CO, NOx and HC from stationary source show no clear trend of increase or decrease. There is no systematic database for the three pollutants in Xi'an. If we assume that three pollutants emission from stationary source stand the same level from 2001 to 2010. Then the following results of mobile source share of total pollution in Xi'an can be made.

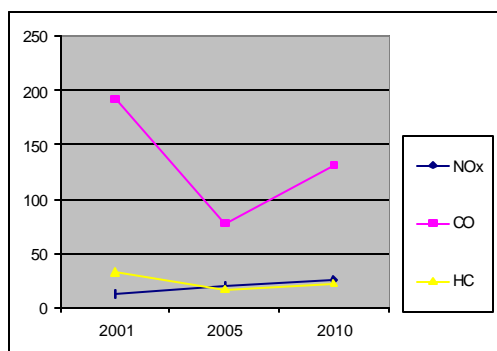


Figure 2: Total vehicle emission
(Unit: *1000 ton)

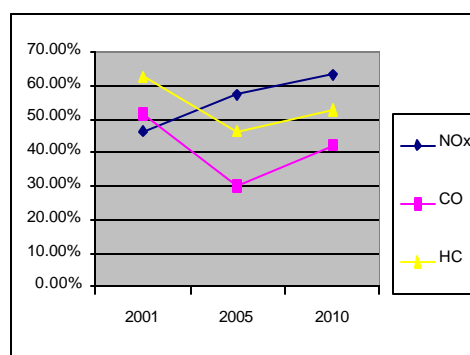


Figure 3: Share of vehicle emission

Based on the estimation above, it is clear that vehicle emission of NOx will increase even if the European standards are adopted, the share of NOx emission by MVs will increase from the present 46.43% to 63.38% in 2010. The new standards will reduce HC and CO emission by a large degree in 2005, but with the increase of MVs, their emission will slightly increase after 2005.

4. Case study 2: Vehicular emission along six roads in Xi'an

Plans for extensive urban road networks are conceived in a determination to eliminate congestion and reduce vehicle emission because of the improvement of traffic flows. International experience of road construction spanning more than half a century can be any indication that it is not true. Building roads is only part of the solution to the complicated urban transport problem and the way to reduce traffic pollution.

Road infrastructure improvement means less emission?

The fact in the Netherlands shows that the construction of road infrastructure facilities has failed to keep up with the growth of road traffic in particular and has resulted in more congestion and environmental problems (Gert Spaargaren, 1997). Many other countries and cities have experienced the same during their development process, whether Beijing or Bangkok. Building roads in cities can reduce traffic congestion and traffic emission is uncertain. In order to have a clear view on vehicular emission at the street level we make the following case study.

Vehicle pollution along six main roads in Xi'an

The data in this part are mainly taken from the environmental impact assessment(EIA) report on the 6 Roads Reconstruction Project in Xi'an City, prepared by Xi'an Institute of Environmental Science and Monitoring Station.

Road traffic emission are the result of three factors: the total volume of traffic; the technical characteristics of the various vehicle types, which influence the emission levels of an average vehicle on the road; and general traffic conditions including operating speeds. Based on it, an estimation was made on the EIA report for the Xi'an Road Infrastructure Project. At present the width of the six roads are between 12-30 meters, and will be broadened to 40-60 meters with separate motor vehicle lanes and bicycle, pedestrian lanes. The traffic volume will increase with the traffic condition improvement.

Table 10: Emission differences under different driving cycle

	Driving cycle	CO (%)	HC (%)	NO2 (%)
Gasoline vehicles	Idle	4.0-1.0	0.03-0.2	0.005-0.1
	Acceleration 0-40 km/h	0.7-5.0	0.03-0.06	0.1-0.4
	Stable speed 40 km/h	0.5-4.0	0.02-0.04	0.1-0.3
	Deceleration 40-0 km/h	1.5-4.5	0.1-0.3	0.0005-0.005
Diesel vehicles	Idle	0	0.005-0.007	0.005-0.007
	Acceleration 0-40 km/h	0-0.1	0.08-0.1	0.08-0.1
	Stable speed 40 km/h	0	0.02-0.1	0.02-0.1
	Deceleration 40-0 km/h	0	0.003-0.005	0.003-0.005

According to the project feasibility study, traffic speed will increase from the present 15-20 km/h to 40-50 km/h after the completion of the project with improved traffic flow according to the project feasibility studies. The emission factors will be reduced with the improved traffic flow.

Table 11: Present traffic flow data, March 9, 2001. (Number of vehicles/day)

	West 1 st Ring road	North 1 st Ring road	East 1 st Ring road	Hua Qing Road	Zao Yuan Road	Zhang Ba Bei Road
Motor vehicles	41927	32106	39284	24310	38151	21098
Bicycles	28995	10740	30292	/	/	/

Table 12: Projected traffic flows (Number of motor vehicles/day)

	2005	2010	2015	2020
West 1 st Ring road	57697	81720	110707	141024
North 1 st Ring road	44856	63533	86069	109639
East 1 st Ring road	54885	77737	105312	134152
Hua Qing Road	33964	48106	65170	83017
Zao Yuan Road	53302	75495	102274	130282
Zhang Ba Bei Road	29477	41750	56559	72048

Table 13: Vehicle emission intensity (mg/meter/second)

		Daily average			Peak hour		
		2005	2015	2020	2005	2015	2020
West 1 st Ring road	CO	27.46	39.63	50.48	30.07	43.39	55.28
	NO2	2.58	3.72	4.74	2.34	4.07	5.18
	HC	2.83	4.08	5.20	2.56	4.46	5.69
East 1 st Ring road	CO	24.25	35.10	44.72	26.38	38.19	48.65
	NO2	2.12	3.07	3.91	1.94	3.34	4.25
	HC	2.71	3.93	5.0	2.48	4.27	5.44
North 1 st Ring road	CO	22.25	30.14	38.4	24.02	32.54	41.45
	NO2	2.25	3.04	3.88	1.92	3.28	4.18
	HC	2.34	3.17	4.04	2.0	3.42	4.36
Hua Qing Road	CO	12.31	21.71	27.65	14.94	26.34	33.56
	NO2	1.39	2.45	3.13	1.25	2.98	3.79
	HC	1.40	2.46	3.14	1.25	2.99	3.81
Zao Yuan Road	CO	18.60	35.69	45.46	20.09	38.57	49.13
	NO2	2.08	4.0	5.09	1.69	4.32	5.50
	HC	1.97	3.78	4.82	1.61	4.09	5.21
Zhang Ba Bei Road	CO	14.21	19.10	24.33	17.23	23.16	29.5
	NO2	1.44	1.94	2.47	1.41	2.35	2.99
	HC	1.56	2.11	2.66	1.54	2.55	3.25

Based on the information above, it is clear that the emission intensity of CO, NO₂ and HC will increase even if the European standards are adopted. If we presume that the pollutants concentration is proportional to the total emission or emission intensity, the street level concentration of these three pollutants will be as high as two times higher than the present.

5. Main pollutants concentration and in-depth analysis

³ TSP and the contribution from urban traffic

According to UNDP306-Xi'an TSP Pollution Control Project report, coal-combustion, urban fugitive dust and motor vehicle particles, the three major sources of particulate pollution, were estimated to contribute 37%, 14% and 20%, respectively to the total TSP in Xi'an. Moreover, the contribution of coal-related pollutants is considerably less, about 25% in both the spring and summer when other pollutants, especially motor vehicle emissions and fugitive and mineral dusts, were the significant contributors to TSP in Xi'an.

If this is the case, reduction of TSP from motor vehicles can significantly reduce the chief TSP pollution in Xi'an. A 50% reduction of TSP from motor vehicles (by certain technical means, e.g. installation of particulate traps on vehicles) means a reduction of TSP concentration by 35 µg.m⁻³ in Xi'an city.

Modeling NO_x concentration at city level

According to Gaussian dispersion model and other pollution modeling methods, it is clear that the concentration at a certain point is linear to the emission intensity from the source. Therefore it is reasonable that we assume the yearly average concentration of NO_x is linear to total emission of NO_x in a certain area, without considering the minor difference of meteorological conditions.

Taken the city of Xi'an as a whole, the total NO_x emission will increase from the present 280,000 tons to 353,900 tons in 2005 and 409,600 tons in 2010, as described in section 3. The average level of NO_x in 2001 is 41 μg.m⁻³. Then we can calculate that by year 2005 and 2010 the average NO_x concentration will increased to 52.1 μg.m⁻³ in 2005 and 59.9 μg.m⁻³ in 2010.

O₃ pollution

The basic mechanisms for the formation of ozone, the reaction of NO_x with hydrocarbons, are firmly established. This does not imply that it is possible to model ozone formation with great precision. Research of Guangzhou NO_x Control Project shows that the ozone concentration in city build-up area is low, and high concentrations of oxidants are often observed in the suburb, frequently over 200 or even 300 mg.m⁻³. Oxidants are very often formulated as the sum of NO₂ and O₃ (Slanina, 2001).

The reason being that ozone in cities reacts very rapidly with NO, most NO is emitted by motor vehicles:



Both NO₂ as well as ozone have clear obnoxious effects that is why the sum of both is taken as total oxidants. Ozone in cities is not only produced by local emissions of VOC and NO_x but that regional contributions further quantification of local and regional contributions will depend on more monitoring results and the use of models.

It is expected that it takes a few hours and hence a transport of at least 20 km, before ozone formation has really developed. So it seems likely that a possible large part of the ozone is advected, this means transported to the down-wind, but originates from emissions outside the city upwind. Reaction of ozone with NO, emitted by traffic is probably responsible for the lower ozone levels directly inside the city. The nitrogen oxide emissions of traffic in the city will lead to increased ozone plumes at distances of some 20 to 100 kilometers. Therefore ozone concentration is difficult to model for the complexities discussed above.

For the lack of data, the ozone level modeling is difficult. Ozone level has never been monitored in Xi'an. The linear relation between NO_x and ozone concentration shows a possible way of modeling ozone. It is not 100 percent scientific correct but it is the only possible way of modeling it due to the limitations mentioned above.

In 1995, the average concentration of NO_x at city level is 138 μg.m⁻³, and O₃ concentration is 150.1ppb in Beijing (Hao Jieming and He kebin, 2000). Xi'an and Beijing both lie in the northern part of China, both experience long and hot summer period. Both cities situated near mountains, the average wind speed in both cities ranges from 1.2 to 2.0 peters per second, which limit the dispersion of pollutants and cause ideal condition for photochemical smog formulation. If the above-mentioned assumption is correct then the following modeling result can be made.

As shown in section 3, the average level of NO_x in 2001 is 41 μg.m⁻³, it will increased to 52.1 μg.m⁻³ in 2005 and 59.9 μg.m⁻³ in 2010. Therefore we can calculate that the average ozone concentration at city level in Xi'an will be 113.3 μg.m⁻³ in 2005 and 130 μg.m⁻³ in 2010.

Beijing and Guangzhou experienced serious ozone pollution due to urban traffic in the last decade. If one takes into account that at ozone concentration of $100 \mu\text{g.m}^{-3}$, it will cause problems to plants and human health, the emerging of ozone pollution problem can be expected in Xi'an in the near future.

Conclusion

Average NOx concentration will increase with the rising NOx emission. If we take the WHO standard of $40 \mu\text{g.m}^{-3}$ as a guideline, NOx is a major pollution concern at present and in the coming decade in Xi'an, even if it has not exceeded the national standard Grade II of $80 \mu\text{g.m}^{-3}$. Ozone pollution will become another problem in Xi'an in the near future. There is an urgent need for the systematic monitoring of ozone concentration at city and street level. Ozone pollution needs to be addressed in future MV pollution control programs in Xi'an city.

6. Suggestions and recommendations for traffic pollution control

Traffic pollution is becoming a main source of urban air pollution in Xi'an. There is an urgent need for traffic pollution strategies. Based on literature review of vehicle pollution control experiences, focusing on technological and policy domain in the world and other Chinese cities, the following integrated comprehensive strategy for Xi'an city is proposed.

Policy levels to control vehicle emissions

Implementing an integrated comprehensive traffic pollution strategy implies that some measures are taken at national level. Ideally, central government should play a major role for setting environmental policies, and the ministries for setting sectoral environmental policies. The State Environmental Protection Administration (SEPA), Ministry of Transport and Ministry of Construction should share and claim their own responsibilities. Currently, SEPA is dealing with urban traffic pollution, setting emission standards, air quality standards, and coordinating with other ministries and local governments.

Regardless of the central government's actions, Xi'an municipality by law is responsible for urban environmental management. With respect to transport related effects, it should exercise control and ensure compliance and enforce measures to mitigate air pollution from automotive sources to protect human health. Nevertheless, an integrated approach to implement proper policies, strategies and measures is necessary to ensure ambient air quality at acceptable levels.

The coordination and cooperation among the different departments of Xi'an municipality should be improved as to traffic pollution control. Under the leadership of Xi'an Environmental Department, other offices such as Urban Planning Bureau, Construction Bureau, Public Utilities Bureau, Public Security Bureau and Transport Bureau should direct their sectoral policies for traffic reduction and vehicle emission compliance improvement.

Integrated approach to control traffic pollution

As was analyzed in previous sections, Xi'an city is increasingly suffering the consequences of pollution from urban traffic. In the cases studied, emission reduction policies have been implemented quite successfully in other urban areas all over the world, improving air quality and reducing the impact on environment and public health. In Xi'an city, there is a great need for the creation of a committee composed of members of the relevant departments, working together to reach solutions and take measures.

Political willingness is necessary to integrate understanding and technical feasibility to solve traffic related environmental problems. Polluter-pays-principle, licensing, control and inspection certificates charges, as well as local budget would be used for financing traffic pollution initiatives and activities.

Implementing a traffic pollution control program means that there must be an enforcement mechanism. Reduction of congestion and improved mobility by regulating traffic flow rely on traffic management. Fiscal and regulatory enforcement measures are necessary to control the vehicle increase and traffic growth. Compliance with emission standards requires the implementation of inspection and maintenance programs along with air quality monitoring network.

Traffic demand management

With the commitment to sustainable development and the recognition of problems described in previous sections it become clear that transport policies had to be modified and directed towards reduction of demand and traffic volume.

Land use planning has influence on travel demand and modal choice. Location of any development of the type which attract many trips, e.g. shopping, higher education, leisure centers, and large offices, should be encouraged to be located within city center, sub-centers, or close to main public transit nodes. Neighborhood planning should be used to help develop more local shops and facilities.

There should be a change at the national policy for encouraging private car consumption. This cannot be settled done by the Xi'an municipal government.

In Xi'an, a lot of work can be done as to the limitation on MV use in the city center. The inner city center is overcrowded and the infrastructure doesn't allow more vehicles to come in. Road pricing for entering the city center or traffic regulation on motor vehicles is the best way in this aspect.

Transport planning and traffic management

A good use of transport planning and traffic management instruments is able to develop an efficient and environmentally friendly urban transport system. Measures aiming at improving traffic circulation can result in substantial fuel savings and pollutant emission reduction. Simple measures like better signing system can reduce congestion and pollution as well.

In the short term:

- ◆ Improve regulations in transport planning to promote a sustainable transport system.
- ◆ Evaluate the road circulation plan, and improve it.
- ◆ Immediate measures aimed at traffic circulation.
- ◆ Segregation of motorized and non-motorized transport.
- ◆ Improve public transport system planning and development.
- ◆ Ban on-street parking along main streets.
- ◆ Restriction on motor vehicles entering the city center by time and vehicle types.

In the long term:

- ◆ Optimize route types, frequencies, fleet size and elasticity of supply.
- ◆ Implement traffic monitoring systems in main roads.
- ◆ Signalization and intersection improvement, using computerized traffic control systems.
- ◆ Formulate an integrated transport plan, which links different kinds of transport means according to future demand and density of local road network.

Public transport development

A well-used public transport is more energy efficient than private cars, particularly for trips to and from the city centers. Encouragement of a modal shift from walking and cycling to public transport, not private cars, should be a priority of municipal authorities. For public transport to be an attractive alternative to cars, it needs to be reliable, efficient, at a reasonable price, convenient, and attractive to use. These objectives can be achieved through the following measures or plans in Xi'an city.

In the short term:

- ◆ Increase on road infrastructure improvement, and give priority to public transport facilities like depots, terminals and stations.
- ◆ Priority given to public buses in traffic control and management system.
- ◆ Bus services can be improved in terms of route covering, frequency and hours of service, etc.
- ◆ Plan and practice on the development of special bus transit lane on main traffic corridors.
- ◆ Speeding up the retrofit program that all buses can run on natural gas.

In the long term:

- ◆ Development of a fast public bus transit system, helping different public transport companies to co-operate on service supply and benefit sharing.
- ◆ Feasibility study and preparation on Subway Line 1 and Light Rail Project, seeking sources of funding for mass transport project construction.
- ◆ Strengthening the planning and management of urban public transport.
- ◆ Promoting the role of science and technology in urban transport development. (Such as computer simulation, use of geographical information system and global positioning system for bus service improvement)

Metro system is an effective and clean public transport system, with high-capacity and fast speed. With urban population growth and an increase of traveling, traditional bus systems and private transport is no longer sufficient for meeting the demand of mobility. There is a great need for a metro system in Xi'an city, which has a population near 4 million at the moment. The construction of a good subway system should be put on the schedule of the public transport development in Xi'an.

Economic instruments and other financial policy measures

Although there is a wide range of financial incentives and disincentives to ensure compliance with air pollution control policies, most of them still cannot be applied in Xi'an due to socio-economic conditions, the availability and efficiency of road networks and the availability of clean fuel stations.

Nevertheless, some economic measures can be applied to influence consumer behavior, while increasing traffic management and improve road network. Although some of these measures depend on central government decisions, they make possible reduced pollution levels in the long term.

In the short term:

- ◆ Lower municipal fees (e.g. annual registration fee) on clean vehicles (e.g. vehicles meet Euro II or III standards), and lower taxes on clean fuels.
- ◆ Incentives for installation of emission control devices (subsidy for the installation), and promote sales of such clean vehicles.
- ◆ Tax deductions for retrofit vehicles with dual fuels or emission control devices.
- ◆ High license fees and taxes for non-compliance vehicles.
- ◆ Area pricing in the city center by installing electronic toll gates.
- ◆ Increase parking fees in city center.
- ◆ Incentives to phase out old vehicles.

In the long term:

- ◆ Mandatory use of low-emission or CNG-fueled vehicles in governmental fleets.
- ◆ A comprehensive economic mechanism for traffic pollution control and reduction of vehicle ownership and use. The income from such pollution control sources should be used to finance clean vehicle and fuel programs.

Inspection and maintenance (I/M) program

Inspection and maintenance programs are proven important for vehicle emission reduction and public safety. Xi'an, as well as the whole nation may need to adapt a compulsory vehicle inspection system with institutional and technical characteristics support to implement this program.

In the short term:

- ◆ Education to improve the technical skills and responsibilities of the employees working at the inspection stations.
- ◆ Strict implementations of present I/M regulations.
- ◆ Gradual retirement of old vehicle.
- ◆ Fines for vehicles not complying with the emission standards and requirement for the installation of emission treatment equipment such as catalysts.

In the long term:

- ◆ Upgrading of emission standards and introduction of improved driving-cycle tests.
- ◆ Incentives for low emission vehicles, e.g. exemption for annual registration fee.

Clean vehicles and fuels

Although new technologies such as catalytic converters and fuel efficient vehicles are being used to reduce toxic pollutants, their introduction should be done gradually according to national vehicle development plans and plans for upgrading vehicle emission standards.

In the short term:

- ◆ Progressive installation of catalytic converters and electronic injection systems for all fossil fuel vehicles, especially for public buses.
- ◆ Reformulation of gasoline and diesel, reducing gradually lead and sulfur content.
- ◆ Retrofit of vehicles on dual fuels, using compressed natural gas (CNG) as an alternative fuel to reduce pollution.

In the long term:

- ◆ Retrofit all public buses and company cars on dual fuels.
- ◆ Research on clean vehicles and fuels.
- ◆ Improve the fuel efficiency and optimize the air-fuel ratio aiming at emission reduction, by multi-point electronic injection system.

Vehicle emission and air quality monitoring

Implementing traffic pollution control programs requires the availability and more importantly, the reliability of data on vehicle emission and ambient air quality. The evaluation of any vehicular pollution strategies requires a well-maintained database on emission sources, types and amounts of pollutants emitted and their spatial and temporal distribution.

Current air quality and emission standards should be strictly enforced with strong interagency coordination to become a successful implementation of the environmental pollution abatement efforts.

In the short term:

- ◆ Establish a monitoring network along main traffic corridors.
- ◆ Establish a database for vehicle emission factors and pollutants concentration along main streets.

In the long term:

- ◆ Acquisition of equipment and procedures complying with the international norms.

Policy on non-motorized transport

Cycling and walking are important modes of transport in their own right. In addition, all car drivers and public transport users are pedestrians at some degree of their journey. Many trips, particularly in urban areas, are short and could therefore easily be made by foot or cycling.

The misconception that cycling is causing traffic congestion should be changed. Because increasing motorized traffic, not cycling, is causing traffic problems, the government's discrimination against non-motorized transport should be eliminated. Non-motorized transport is not the image associated with poverty. The renaissance of bicycles in some European countries, such as the Netherlands, France, Germany, and Denmark etc., show a trend that we need to analyze. In these highly developed countries, non-motorized transport has been emphasized as a clean transport means as to environmental consequences. This growing emphasis might help policy-makers in Xi'an and other Chinese cities to rethink about their policies against bicycles.

Cycling, walking and bike parking facilities can be improved to enable cyclists and pedestrians to travel more safely and in less-polluted environment. The provision of purpose-built cycle facilities, cycle lanes, signals, street lighting, signing and cycling parking, designing new and revised road schemes with pedestrians and cyclists in mind, traffic calming measures, lower speed limits, pavement improvements and better road crossings, are all important means of encouraging and enabling people to make more trips on foot or by bicycle.

The huge number of bicycles in Xi'an has significant positive impacts on the ambient environment, and so must be included in any analysis and decision-making as to transport.

Regulatory and economic instruments and their effects on the traffic and environment

There are many factors that interact and contribute to the total vehicle emission. The following two tables give a clear relation between these factors and their effects on some main traffic and pollution indicators. This list can serve as a useful reference for future policy instruments selection.

Table 14: Regulatory, economic policy instruments and transport indicators

		Vehicle ownership	Kilometers driven	Kilometers by public transport	Fuel consumed
Regulatory policy instruments	Emission standards	Little effect	No direct effect	No direct effect	Decrease
	Road infrastructure construction	Increase	Increase	Small reduction	Possible increase
	Traffic calming	No direct impact	Reduction in certain area	No direct effect	Possible increase
	Vehicle use restriction	Reduction	Reduction in certain area	Increase	Reduction
	Scrap regulation	Reduction of old MV fleet	Possible reduction	Possible small increase	Reduction
	Parking controls	Small reduction	Reduction in certain area	Small increase	Possible decrease
	Land use planning	Reduction if successful	Reduction if successful	Clear increase if successful	Reduction if successful
Economic instruments	Fuel taxes	Reduction (move to small or efficient vehicles)	Reduction total	Increase total	Reduce total
	Emission taxes	Switching to less polluting vehicles	Small reduction	Possible increase	Small reduction
	Variable vehicle exercise taxes	Reduction	No direct effect	Possible increase	Reduce total
	Road congestion pricing	Small reduction	Reduction in certain area	Possible increase	Reduce total
	Parking charges	Small reduction	Reduction in certain area	Possible increase	Not clear
	Public transport subsidies	Small reduction	Reduce total	Clear increase	Decrease

Table 15: Regulatory, economic policy instruments and environmental indicators

		On CO2 emission	On NOx, HC and CO	On traffic congestion
Regulatory instruments	Emission standards	Reduction	Reduction	Little effect
	Road infrastructure construction	Increase	Not clear Possible increase	Reduction first and possible increase later

	Traffic calming	Possible increase	Possible increase in HC and CO, decrease in NOx	No direct effect
	Vehicle use restriction	Reduction	Reduction	Reduction
	Scrap regulation	Reduction	Reduction	Possible reduction
	Parking controls	Possible decrease	Possible reduction	Not clear
	Land use planning	Reduction if successful	Reduction if successful	Reduction if successful
Economic instruments	Fuel taxes	Reduce total	Reduce total	Reduce total
	Emission taxes	Reduce total	Reduce total	Possible reduction
	Variable vehicle exercise taxes	Reduce total	Small reduction	No direct effect
	Road congestion pricing	Reduce total	Reduce total	Clear reduction
	Parking charges	Not clear	Possible reduction	Reduction in certain area
	Public transport subsidies	Decrease	Possible reduction	Reduction

Public participation in policy-making on traffic pollution control

Research has shown that the participatory and transparent environmental management by citizens, professionals, NGOs and other social organizations is more effective and efficient than the former command-and-control style of policy making by the environmental authorities or relevant governmental offices. Traffic pollution programs will not succeed without the participation of the public, because they are public transport users, drivers, walkers, or cyclists whose decisions are determinants of traffic pollution. Policies or decisions made by the large public can improve the success of such pollution control programs because of the initiatives from the public.

Xi'an municipal authorities can improve in this aspect. The municipal government can launch discussions on traffic management and pollution control, use propaganda for transferring information concerning motor vehicle pollution, and raise environmental awareness among citizens by suggesting green transport means or clean vehicles. Prior to promulgation of any policy or decision, there should be a process of public involvement and participation.

Implementation issues

A policy considered important in isolation may be ineffectual because the countervailing impact of other factors. For instance, mandating strict emission standards without providing unleaded gasoline would be impractical since the primary means of meeting such standards, catalytic converters, functioning only with unleaded gasoline. And any demand management policy designed to dampen private motorized travel would function only if viable public transport were provided. As such, a supply of public/alternative transport is an indispensable part of the strategy. Less obviously, programs such as inspection and maintenance require more than physical space and equipment. Administrative capacity, including adequate training, staff, and competence are essential; yet they are sometimes

overlooked. It is therefore important to design complementary policies in a manner that integrates public and private transport, and combines supply-side and demand-side.

Ideally, measures should address not just the transport sector, but also all the related areas of land use planning, transportation need and modes, and air quality. Land use planning that encourages large employees to locate near residential districts may reduce travel demand and subsequent emissions. Also high-density urban corridors have been shown to be amenable to cost-effective public transport (Midley, 1994).

As mentioned earlier, the success of a policy may itself perverse incentives. Paving dirt roads in order to ease particulates from resuspension and improving driving conditions may well raise the demand for travel. Likewise, relieving traffic congestion tends to attract more drivers since private travel becomes more efficient. Even emissions standards may send unintended signals. First, they may reduce fuel economy, and thereby raise consumption and CO₂ emissions. Second, they provide no incentive for additional marginal emissions reduction once the standard is met, even if further reduction could be attained easily.

In addition, it is vital to ensure that incentive structures are compatible. For example, raising gasoline taxes to reflect the true social cost of using gasoline would have favorable impacts on passenger travel and fuel efficiency. However, if a substitute such as diesel fuel were not taxed and remained substantially cheaper, then the gasoline tax policy would lose its punch as consumers switched to the cheaper fuel.

Finally, some instruments that permeate the full range of motorized transport systems can enhance virtually any abatement policy. Fuel taxes imposed on all fuels can help dampen demand, and they pay abatement dividends when used in concert with other policies, such as road pricing or fuel reformulation. As such, fuel taxes in tandem with other policies are nearly always a good combination (Eskeland and Devarjan, 1996).

7. Conclusion

Urban traffic in Xi'an will increase with the urban growth and increase of motorization. The current urban transport system has caused serious traffic congestion, and the vehicle emission has become one of the major pollution sources in Xi'an. Based on the estimation done in this study, the share of NO_x, HC and CO pollution from urban traffic in Xi'an stands at around 46.43%, 62.47% and 51.64% at present. The study also shows that vehicle emission of NO_x will increase even if the strict vehicle emission standards are going to be adopted, the share of NO_x emission from traffic will increase to 63.38% by 2010. The introduction of new standards will reduce HC and CO emission by a large degree by 2005, but with the increase of vehicle population and kilometers driven, their emission will slightly increase after 2005.

Traffic pollution is becoming a main source of urban air pollution in Xi'an. There is an emergent need for traffic pollution control strategies. Studies on transport and emission control often take a technological focus. Improvement in vehicle technology can help reduce emissions considerably, but it will be offset by the increase of vehicle ownership and kilometers driven, as shown in this study. The other objective in most urban areas is to reduce transport demand by planning, regulatory and fiscal measures. Experiences from different countries and cities have shown that there is no single unambiguous and effective remedy. Because there are so many complex factors interacting in the transport sector's effect on pollution, a holistic approach is necessary, that is, a combination of all the types of policy measures.

Improvement in vehicle technology can help reduce emissions considerably. Installation of catalytic converters and electronic injection system are two important available technologies for emission reduction. Retrofit of in-use vehicles on CNG fuels is another way for pollution control. Fuel quality improvement and alternative fuels can reduce vehicular emission substantially. As shown by this research the emission reduction by technology improvement will be offset by the increase of motor vehicle ownership and kilometers driven.

The growth of urban economy depends on a safe, efficient and economical urban transport system. People should be encouraged to adopt a mode that is both environmental friendly and resource saving. Public transport is a priority that should be popularized on a large scale, it should be developed both in the light of policy and investment support, and also of transport management, road usage and traffic light control. The protection of bicycle and pedestrian transport should be emphasized. The use of private vehicles should be rationalized. The personal use of private vehicles in downtown area in Xi'an should be limited to reduce congestion and pollution.

Land use planning and economic measures can help reduce transport demand. Urban land use and physical planning can to some degree reduce the demand for travel to work, shopping and leisure etc. Transport pricing instrument should be emphasized. Urban transport pricing policies should support the sustainable development of transports system. The income from these taxes and levies ought to help improve environmentally friendly transport mode, such as public transport and non-motorized transport.

Vehicle emission control should be strengthened by strict enforcement of present vehicle emission standards and regulations. There is a great need for upgrading of present vehicle emission standards, and I/M programs. The inspection and maintenance should be in line with the new standards and test procedures and requirements. Installation of catalytic converters and electronic ejection system are two important available technologies for emission reduction. Retrofit of in-use vehicles on CNG fuels is another way for pollution control. Fuel quality improvement and alternative fuels can reduce vehicular emission substantially.

Land use planning and economic measures can help reduce transport demand. Urban land use and physical planning can to some degree reduce the demand for travel to work, shopping and leisure etc. Fiscal policies can support the sustainable development of transports system, encouraging public transport development and non-motorized transport use, and limiting the use of private cars.

Implementing a traffic pollution control program means that there must be an enforcement mechanism. Reduction of congestion and improved mobility by regulating traffic flow rely on traffic management. Fiscal and regulatory enforcement measures are necessary to control the vehicle increase and traffic growth. Compliance with emission standards requires the implementation of inspection and maintenance programs along with air quality monitoring network. Vehicle emission control should be strengthened by strict enforcement of present vehicle emission standards and regulations. There is a great need for upgrading of present vehicle emission standards and I/M programs. The inspection and maintenance should be in line with the new standards and test procedures and requirements.

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