Development of High-Resolution Motor Vehicle Emission Inventories for City-Wide Air Quality Impact Analysis in China

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ABSTRACT

In recent years, large cities in China face severer air pollution due to motor vehicle emissions. Accurate high-resolution emission inventories are essential as they are commonly used in air quality dispersion modeling analysis to determine impacts from motor vehicle emissions and assess the effectiveness of control strategies.

This paper presents a case study based on motor vehicle emissions in the City of Hangzhou, China. A method was developed to estimate the spatial and temporal distributions of motor vehicle emissions based on the best available database to the research team. The distributions of Vehicle Kilometers Traveled (VKT), vehicle age, type and technology classes operating on city streets were determined based on records obtained from various sources including on-scene video tapes, traffic count statistics, and Inspection and Maintenance (I/M) station database. The vehicle driving patterns were measured using the Global Positioning Satellite (GPS) technology. The International Vehicle Emission model (IVE) combined with Geographic Information System (GIS) was used to develop high-resolution spacial (1 km × 1 km) and temporal (hourly) emission inventories of CO, HC, NO_x and PM_{10} from motor vehicles in Hangzhou in 2004. These high-resolution emission inventories in Hangzhou were used as inputs to the USEPA's AERMOD model to simulate the concentration distributions caused by motor vehicle emissions.

This paper details how to select the appropriate emission factor model, how to collect and analyze vehicle activity data, and allocate emissions spatially and temporally. The resulting vehicular emissions distributions and their effects on the urban air quality in the city are also discussed.

INTRODUCTION

With an annual vehicle fleet growth rate of more than 20% in Chinese major cities in recent years, China faces severer motor vehicle pollutions. The State Environmental Protection Administration of China (SEPA) has identified motor vehicles emissions as the major source of urban air pollution in China[1]. In 2004, on-road vehicles were estimated to contribute over 50% of the nitrogen oxides (NO_x) to large cities' emission inventories[1]. As a result, regulators and decision makers are being required to invest significant resources into managing and assessing roadway effects on air quality.

To better quantify the impacts on air quality by on-road motor vehicles or assess the effectiveness of control strategies, accurate high-resolution emission inventories are needed as the inputs to air dispersion models. However, due to the limited database of motor vehicle activities (including VKT distributions, vehicle fleet age, type and technology distributions etc.) and lack of a comprehensive motor vehicle emission model in China, emissions from motor vehicles in Chinese cities are not well quantified. Furthermore, there is no established quantification method to project future emissions. As a result, decision-makers are unable to design effective control strategies to improve air quality caused by the complicated urban area motor-vehicle emissions.

Hangzhou, the capital of Zhejiang Province (a well-developed coastal province in China) and a major city in Yangtze Delta, has an urban area of 730 km^2 and a population of more than 2 million people (not including the floating population). The Gross Domestic Product (GDP) of Hangzhou city in 2004 was 194.9 billion Yuan (RMB), accounting for 23% of Zhejiang's total GDP and 1.48% of China's total GDP, respectively. With the economic growth, the vehicle population in the Hangzhou urban area has increased sharply in recent years. By the end of 2004, the vehicle population had reached 230,000 (of which more than 94% are automobiles), with an average annual growth rate of 27.8% from 2001 to 2004.

Based on the roadway systems and motor vehicle conditions in Hangzhou, a series of research studies were conducted to quantify the base year motor vehicle emissions and assess the impacts on urban air quality. The results would be used in the development of air quality management plans for the region.

This paper provides a summary of the series of studies in the context of the special situation in China with the following objectives:

- Identify an appropriate motor vehicle emission model to improve the estimation of motor vehicle emission factors.
- Improve the accuracy in estimating the motor vehicle activity levels with limited data sources.
- Develop spatial and temporal emission inventories for roadway motor vehicles, which could be used directly as the inputs of an urban air quality model.

IDENTIFICATION OF APPROPRIATE MOTOR VEHICLE EMISSION MODEL

Vehicle emission factors depend on many considerations, which can be grouped as vehicle emission control level, vehicle type and fuel type, utilization parameters (e.g., age, accumulated mileage, inspection and maintenance), operating modes (e.g., speed and start distributions, air conditioning), and ambient parameters (e.g., temperature and humidity). Therefore, it is necessary to use a comprehensive emission model to estimate the emission factors of motor vehicle fleets.

Since Chinese motor vehicle emission control is in its early stage and lack of adequate emission data accumulation and the resources to conduct enough systematic emission testing and analysis, no China-specific motor vehicle emission model was developed. At present, most applications in China are based on the overseas emission models, such as MOBILE, EMFAC and COPERT.

As the first mobile source emission model introduced into China, USEPA's MOBILE model series has been modified and widely used in developing mobile source emission inventories in the past decade in both city and country level by several Chinese research institutes[2-6]. However, these applications have apparent limitations:

- As the key factors in the mobile source emission model, the zero mileage level (ZML) and vehicle deteriorate rate (DR) parameters of the base emission factors (BEFs) are determined by the model year in the MOBILE program. As such, once the model year is determined, the BEFs of different vehicle types are determined. Although some dynamometer testing has been conducted in China, the number of tested vehicles is quite limited (e.g., 171 tests in Beijing by Tsinghua University[6]) and the results cannot be directly used to modify the BEFs in the outdated MOBILE5 program. To determine the appropriate BEFs, ZML and DR were selected from those in MOBILE5 model for the model year which was matched to the emission control level in China[6]. Obviously, these are rough estimations of BEFs, since the distributions of fuel injection type and control technology for one model year in China can not match well with those in the U.S. In addition, for MOBILE6, the modification of BEFs is very complicated and not recommended by USEPA.

- The MOBILE model is an average-speed based emission factor model. In recent years, it is widely accepted that speed alone is not a good indicator of vehicle power demand. Vehicle acceleration consumes considerable energy and is not indicated by average vehicle speed. To develop high-resolution temporal and spacial emission inventories for air dispersion modeling, more precise emission factor models are required.
- The vehicle type classification in MOBILE6 is detailed and quite different from that in China, which limits the use of existing vehicle registration data and more surveys and analysis have to be conducted.

Besides MOBILE, California Air Resources Board's EMFAC model series and European Union's COPERT model series have also been utilized in China[7-9]. Especially designed for the California State, the EMFAC model has lots of typical functions to model the vehicle emissions from 14 basins and 58 counties in the area of California. HK EPD has adopted a modified EMFAC, called EMFAC-HK, to estimate motor vehicle emissions[10]. However, this model is not widely used in the continental China, because the technology categories and input data requirements in EMFAC are more complicated than those of MOBILE. The COPERT model is the most commonly used model in Europe, but not widely used outside the region. Compared to its American counterparts, COPERT has the advantage of similar testing procedures and similar vehicular pollution control standards system for new vehicles when being applied in China. The limitation is that as a statistical model based on average speed, the actual driving cycles can not be accurately reflected and the testing cycles are only comprised of constant speed, constant acceleration and constant deceleration, which are much simpler than the American ones.

As one of the new generation models, the International Vehicle Emissions (IVE) Model developed by University of California at Riverside, College of Engineering-Center for Environmental Research and Technology (CE-CERT) is specifically designed to have the flexibility needed by developing countries in their efforts to address mobile source air emissions. The first version is published in 2003, and since then it has been applied in several cities worldwide including Beijing and Shanghai, China[11-12]. Besides, on road emission measurements by Portable Emission Measurement System (PEMS) in cities of several developing countries were conducted to calibrate and improve the model[13]. The latest version is IVE 1.2.2, published in January 2008. Compared to the models mentioned above, IVE model has its advantages in the following aspects:

- The BEFs in IVE model are determined directly by the vehicle technology, which is defined by the engine air/fuel management technology and engine size, emissions control technology, fuel type and accumulated use of vehicle. It is easier to determine the BEFs more accurately in IVE model. In addition, IVE model also provides an optional sheet for users to add their own BEFs based on enough number of local measurements.
- Instead of only average-speed adjustment, vehicle specific power (VSP) and engine stress distributions are also introduced into IVE model. It is proved that about 65% of the variance in a vehicle's running emissions can be accounted for using VSP.
- Different from MOBILE6, the vehicle classification in IVE model can be just defined as passenger cars (PC), truck, bus, taxi and motor cycle (MC), which is easier for activity data collection and analysis.

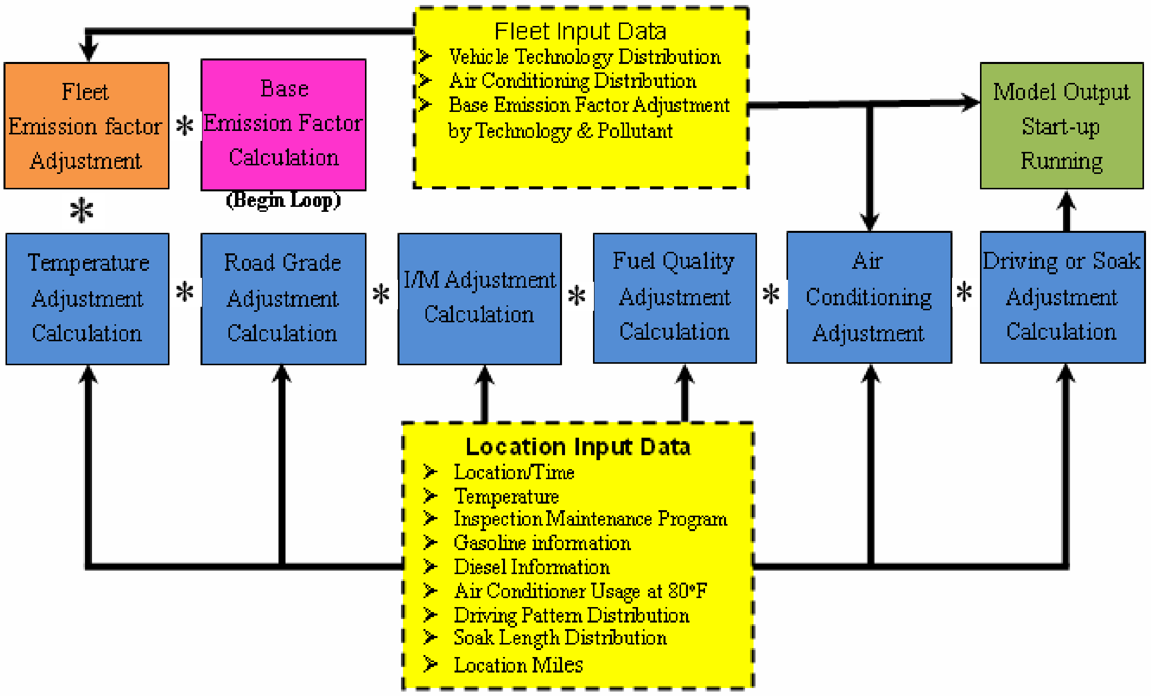
Although, the IVE model is not as mature as the MOBILE model, it is more suitable for the situation in China. In this study, the IVE model combined with GIS system was used to develop high-resolution emission inventories from motor vehicles in Hangzhou.

Overview of IVE model

Figure 1 illustrates the process of estimating emissions in the IVE model. The basis of the emission prediction process of the IVE model begins with a base emission rate and a series of correction factors are applied to estimate the amount of pollution from a variety of vehicle types. There are three critical components that are used in the IVE model to create accurate emissions inventories:

1) Vehicle emission rates (Base Emission Factor and Correction Factors);
2) Vehicle activity (Location Input Data shown in Yellow Box); and
3) Vehicle fleet distribution (Fleet Input Data shown in Yellow Box).

Figure 1. Model core architecture



Base Emission Factors (BEFs)

There are two types of BEFs, one for running emissions and the other for start emissions. In theory, the same technology vehicle operating under the same environmental and fuel characteristics should produce roughly the same emissions. Vehicle technology distribution determines BEFs of each vehicle type. In this study, running BEFs of petrol vehicles were adjusted by the on-site remote sensing measurements in Hangzhou[14]. Since there are no on-site emissions measurements on diesel and other fuel-based vehicles, the original BEFs of these vehicle technologies in IVE model were directly adopted. Start BEFs were also from original BEFs in IVE model.

IMPROVEMENT OF VEHICLE ACTIVITY STUDY

As the major inputs in mobile source emission models, vehicle activity data is critical for accurate emission estimation. Nevertheless, since vehicle emission control is just beginning in most Chinese cities, the systems for traffic monitoring and vehicle inspection and maintenance (I/M) data collection and statistical analysis are not well developed and the existing database is insufficient. Therefore, how to collect representative data in an efficient way is becoming very important.

In this work, some surveys and measurements were conducted, combining with the existing vehicle registration database, and I/M database to determine these vehicle activities:

1) Traffic flow and vehicle fleet composition,
2) Vehicle technology distribution,
3) Vehicle driving patterns, and
4) Vehicle start patterns.

Division of the Study Area

Since it is impossible to conduct surveys in every road link, it is necessary to select representative roads in homogeneous neighborhoods. In other studies[11-12], a low income, an upper income and a commercial area were selected as representative study areas for surveys. However, in Hangzhou, there are no distinct upper or lower income areas. Instead, like most Chinese cities, Hangzhou has been expanding its area from its central area to its surroundings areas. Traffic jams typically occur in the central area, while most new building constructions and new roads concentrate at the newly developed area, which determines the different traffic intensity and different vehicle fleet composition for the same street type but different zones. Therefore, in this study, Hangzhou urban area that is composed of six districts was divided into three zones based on both road network intensity and population intensity, as shown in Figure 2. The three zones covers 81km^2, 165km^2 and 510km^2, respectively. In each zone, three representative roads were selected to conduct local surveys. They are:

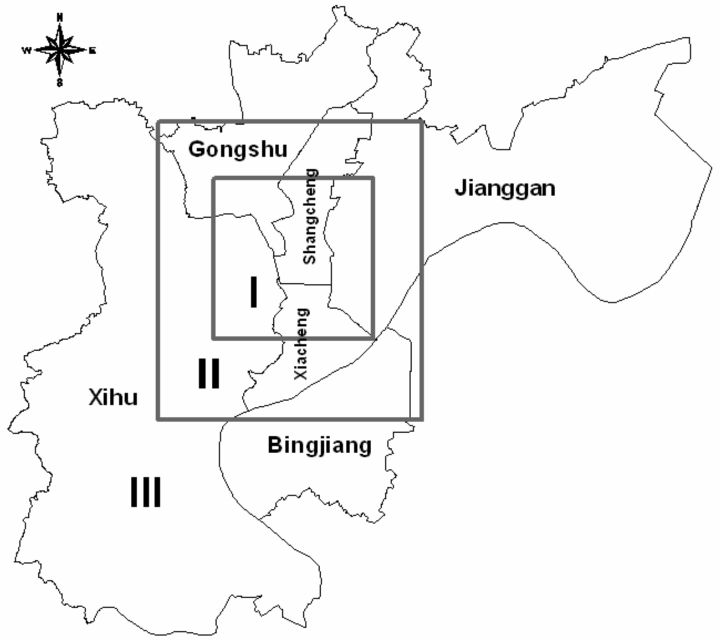
1) Highway and elevated road across the urban area (usually 8 lanes),
2) Arterial way in the urban area (usually 4 or 6 lanes, most of them are 4 lanes in Hangzhou), and
3) Residential way in the urban area (usually 2 lanes).

It is assumed that the traffic volume distributions and vehicle fleet compositions are similar for the same road type in the same zone.

Survey Approach

The technology distribution of vehicles was developed using a combination of two approaches. Vehicles were video-taped on nine road links from the three parts and the videotapes were reviewed to count the numbers of the various types of vehicles operating on Hangzhou streets. Video-traffic surveys were carried out from 06:00 to 22:00 over 7 days in the three sections of the urban area to provide traffic volume and vehicle fleet composition information for different hours of the day. Since no data was collected between 0:00 and 5:00, and between 23:00 and 0:00, these values were estimated using fractions observed in other Chinese urban areas[11-12].

Figure 2. Division of the studied urban area of Hangzhou city



To understand the specific technologies of local vehicles, I/M station surveys were conducted for all workdays in January 2005 by the staff in Hangzhou's six I/M stations. Vehicles were inspected to collect the information of the engine type, fuel type, model year, control equipment and vehicle usage can be established. The I/M stations surveys were used to estimate the more specific natures of the general vehicle classifications determined from the video tape studies.

Simultaneously the vehicle engine start patterns were collected by investigating vehicle users in I/M stations regarding how many times vehicles start the day before the survey day, when vehicles start and how long they stay idle between starts. This information is used to develop vehicle start pattern distributions.

The driving patterns for various classes of vehicles were measured using Global Positioning Satellite (GPS) technology. This technology allows for the second by second measurements of vehicle speeds. One passenger car with GPS units was driven along selected roads from 07:00 to 20:00 during a week to provide driving pattern information for different hours of the day. Two taxis with GPS units operated on their normal daily route throughout Hangzhou. For bus, second by second vehicle speed data of six selected buses that travel in different areas were obtained from the GPS platform of Hangzhou Public Transport Group Co. Ltd.

The vehicle population and vehicle registration distribution data were obtained directly from Hangzhou Vehicle Management Bureau's I/M database and Hangzhou Vehicle Emission Administration's vehicle registration database. The other parameters including fuel characteristics, ambient meteorology, use of air conditioning as well as I/M programs are all determined according to Hangzhou's local situation.

Survey Results

Traffic Flow and Vehicle Fleet Composition

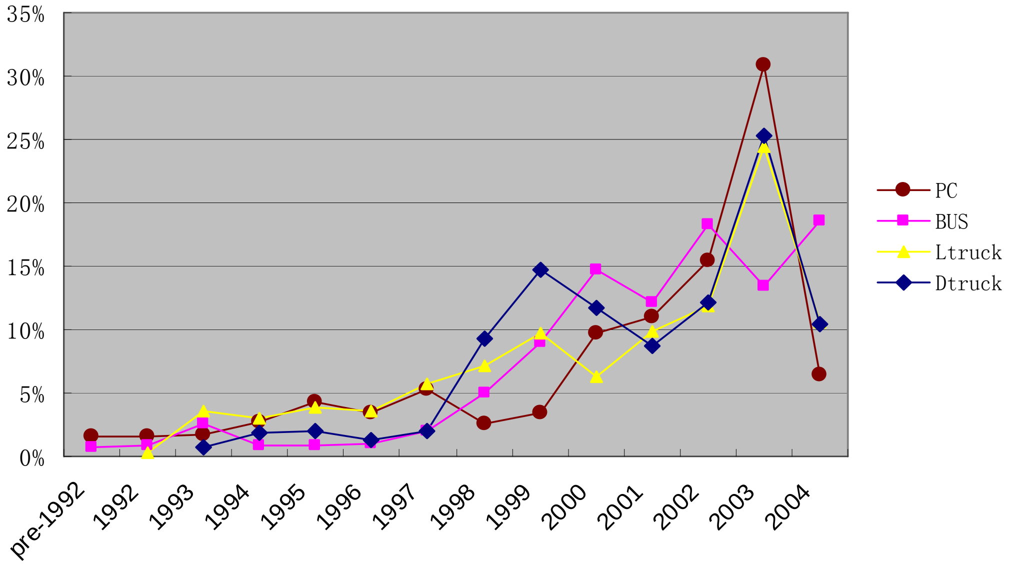
The summary of the video-tape survey results is shown in Table 1 Since 2000 (when a rule was promulgated in Hangzhou to forbid motorcycle registration in the urban area), the population of motorcycles has been decreasing. By 2004, there were only 12,200 motorcycles which accounts for 5.35% of the total vehicular population and the motorcycles operating on city streets are less according the video-tape survey. In addition, the vehicle population distribution is also shown in Figure 3.

Table 1. Summary results of surveyed traffic flow and vehicle fleet composition

Road type	Vehicles/h	Passenger cars	Taxi	Bus	Dtruck	Ltruck	MC
Overall highway	3180	65.96%	18.98%	5.02%	5.01%	5.03%	0%
Overall Arterial way	1954	57.17%	27.72%	7.84%	1.52%	2.85%	2.90%
Overall Residential way	421	60.17%	34.19%	1.78%	0.29%	1.87%	1.70%

* Dtruck, heavy –duty truck; Ltruck: light-duty truck

Figure 3. Motor vehicle registration distribution in Hangzhou in 2004



Vehicle Technology Distribution

Information of 4849 vehicles was collected in the I/M station surveys, including 1,901 passenger vehicles, 187 taxis and 1,969 trucks to develop the technology distribution of these vehicle categories. Hangzhou Public Transport Group Co. Ltd. provided the technology distribution of the bus fleet. Table 2 presents the general characteristics observed in the surveyed fleet.

Table 2. Technology distribution of motor vehicles in Hangzhou

Vehicle Type	Fuel Type	Air/fuel system	Emission control	Fraction	Total
PC	Gasoline	Carburetor	No Catalyst	20.8%	100%
			2-way Catalyst	6.5%	
		SPFI	2-way Catalyst	4.4%	
			3-way Catalyst	11.9%	
		MPFI	3-way Catalyst	53.7%	
	Diesel	Direct injection	EGR	2.7%	
Taxi	Gasoline	MPFI	3-way Catalyst	91.7%	100%
	Diesel	FI	EGR	8.3%	
Bus	Gasoline	Carburetor	No Catalyst	17.7%	100%
		FI	Euro Ⅰ	8%	
	Diesel	Direct injection	Improved	13.3%	
		FI	Euro Ⅰ	51.0%	
		FI	Euro Ⅱ	9.8%	
Ltruck	Gasoline	Carburetor	No Catalyst	11.7%	100%
		FI	Euro Ⅰ	9.6%	
		FI	Euro Ⅱ	4.4%	
	Diesel	Pre-Chamber	None	23.6%	
		FI	Euro Ⅰ	44.4%	
		FI	Euro Ⅱ	6.36%	
Dtruck	Gasoline	Carburetor	No Catalyst	14.6%	100%
	Diesel	Direct injection	Improved	68.7%	
		FI	Euro Ⅰ	26.5%	

* SPFI，Single Point Fuel Injection; MPFI, Multipoint Fuel Injection; FI, Fuel injection

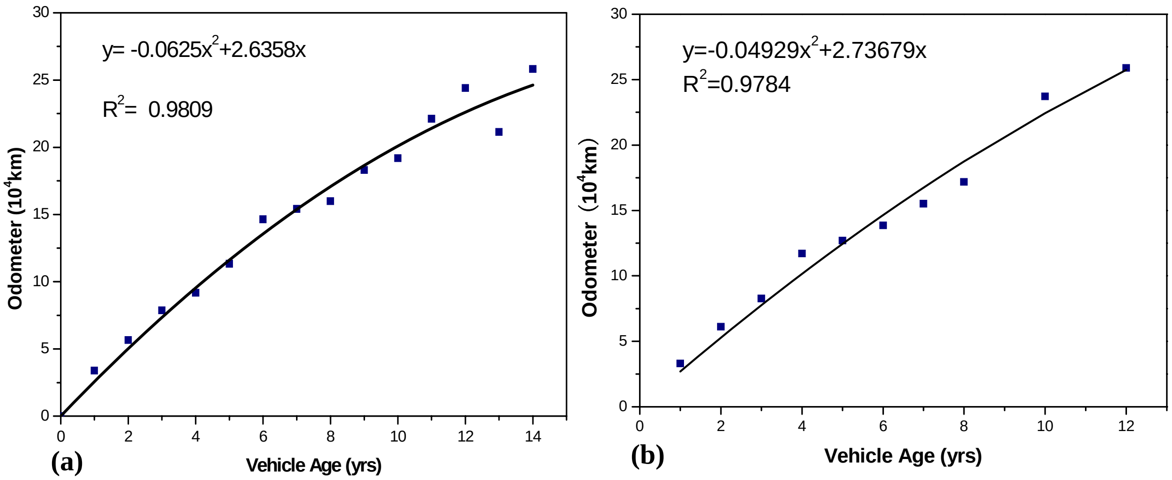
Table 3 indicates the engine size and use distribution of the passenger vehicles in Hangzhou. Information in Table 3 must be combined with information in Table 2 along with the video collected data in Table 1 to produce the vehicle fleet technology distributions for estimating emissions.

Table 3. Size and use characteristics of Hangzhou Fleet

Vehicle type	Exhaust volume/ Vehicle weight	Vehicle use			Total
		<80,000 km	80,000-160,000 km	>160,000 km	
PC	Light（<1500cc）	8.4%	3.6%	2.4%	14.4%
	Medium（1500-3000cc）	48.6%	20.6%	14.3%	83.5%
	Heavy（>3000cc）	1.2%	0.5%	0.4%	2.1%
	Total	58.2%	24.7%	17.1%	100%
Taxi	Medium（1500-3000cc）	20.1%	12.37%	67.53%	100%
Bus	Light（4.1-6.4t）	3.7%	2.6%	4.5%	10.8%
	Medium（6.4-15t）	31.9%	19.7%	37.6%	89.2%
	Total	35.8%	22.1%	42.1%	100%
Ltruck	Light（<2.3t）	15.8%	18.7%	8.22%	42.8%
	Medium（2.3-3t）	20.9%	6.9%	3.2%	31%
	Heavy（3-4.1t）	11.58%	7.72%	6.93%	26.2%
	Total	48.3%	33.4%	18.3%	100%
Dtruck	Light（4.1-6.4t）	17.1%	12%	8.8%	38%
	Medium（6.4-15t）	25.3%	20.6%	16.2%	62%
	Total	42.4%	32.6%	25%	100%

The annual mileage accumulation rates of different vehicle types were calculated by regressing cumulate mileage and vehicle ages. Figure 4 shows the regression plots for PCs and Ltrucks based on more than 4,000 vehicle data. Each point in the plots is the average cumulate mileage of vehicles in that age. These results can be used to estimate the total annual mileage traveled in the model year, combing with vehicle age distribution.

Figure 4. Vehicle use during the first fourteen years of age: (a) PC (b) LTruck



Vehicle Driving Patterns

The vehicle driving pattern measurements were carried out to calculate VSP and engine stress distributions. Equation (1) and Equation (2) are used to calculate the VSP and engine stress, respectively, in the IVE model.

Equation (1) $VSP = v \times [1.1 \times a + 9.81 \times \arctan(\sin(grade)) + 0.213] + 0.000305 \times v^3$

where:

VSP— Vehicle specific power

v — Instantaneous vehicle speed

a — Instantaneous vehicle acceleration

Equation (2)

$$EngineStress(unitless) = RPMIndex + (0.08ton / kW) \times \Pr eaveragePower$$

$$\Pr eaveragePower = Average(VSP_{t=-5\sec to -25\sec})(kW / ton)$$

$$RPMIndex = Velocity_{t=0} / SpeedDivider(unitless)$$

$$Minimum(RPMIndex) = 0.9$$

Ultimately the GPS data for each vehicle type studied is broken into one of the 20 VSP bins and one of the 3 STR bins. As such, each point along the driving route can be allocated to one of the 60 driving bins. Table 4 illustrates one of the distributions of driving bins in this study. Power Bins 1-11 represent the case of negative power (i.e. the vehicle is slowing down or going down hill or combination of these coditions). Power Bin 12 represents the zero or very low power situation such as waiting at a signal light. Power Bins 13 and above represent the situation where the vehicle is using positive power (i.e. driving at a constant speed, accelerating, going up a hill or some combination of these conditions)

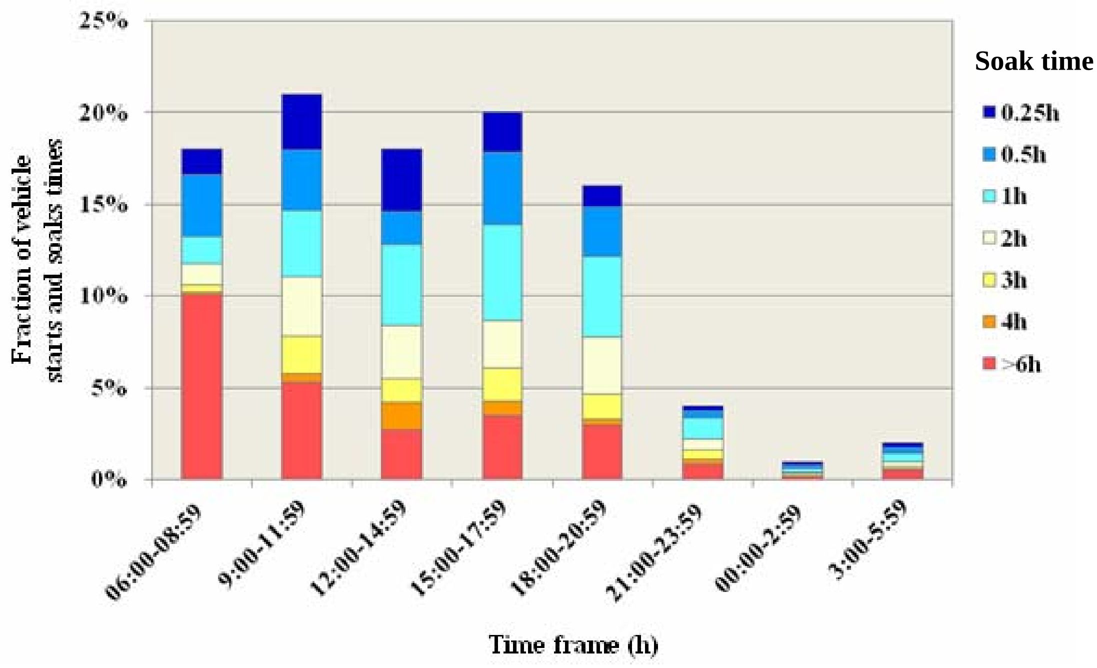
Table 4. Distribution of driving into IVE power bins for vehicles operating on arterials averaged in Hangzhou (7:00-20:00, average speed: 17.89 km/hour)

Stress (STR) Bin	**Distribution of Driving at Each Power (VSP) Bin**									
Low	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
	0.11%	0.02%	0.03%	0.04%	0.07%	0.10%	0.22%	0.38%	0.96%	2.59%
	11	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
	11.09%	53.06%	15.33%	7.31%	2.66%	0.90%	0.50%	0.26%	0.23%	0.73%
Media	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
	0.01%	0.00%	0.00%	0.00%	0.00%	0.00%	0.01%	0.01%	0.02%	0.05%
	11	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
	0.14%	1.11%	0.35%	0.17%	0.08%	0.07%	0.05%	0.06%	0.03%	0.34%
High	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
	0.01%	0.00%	0.00%	0.00%	0.00%	0.00%	0.01%	0.00%	0.00%	0.01%
	11	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
	0.05%	0.61%	0.10%	0.05%	0.02%	0.01%	0.00%	0.01%	0.00%	0.03%

Vehicle Start Patterns

A total of 522 effective questionnaire sheets were collected in this study, among them 292 for PC, 176 for truck and 54 for taxi. Based on this data, it is found that the daily start times is 7.1, 5.5 and 3.2 for PC, truck and taxi, respectively. Figure 5 illustrates the PC start times and soak time distributions in Hangzhou.

Figure 5. Vehicle start patterns in Hangzhou



ESTIMATION OF THE SPATIAL AND TEMPORAL EMISSIONS

VKT Allocation

Temporal and spatial vehicle emissions are determined by the emission factors and distributions of VKT. In developed countries, travel demand models (TDMs) are typically used to allocate distributions of VKT. Nevertheless, TDMs depend on previous calibration of the estimated traffic fluxes with empirical data, and require substantial financial and time resources to be developed. In this study, the VKT is allocated by treating highway and arterial streets as line sources and residential ways as area sources, since traffic flow data of small roads are not available. This concept was first proposed by Hao[6].

The VKT of line sources can be allocated directly by on-site traffic counting, while the VKT of area sources are allocated by dividing the network of residential streets into grids and introducing population density and length of roads as allocation indicators. The algorithm of mileage allocation is described by Equation (3).

Equation (3) $$M_j = (\alpha K_j^1 + (1-\alpha)K_j^2) \times M$$

where,

M_j –mileage traveled by area mobile sources in grid j， km；
M – total mileage traveled by area mobile sources， km；
α – a parameter which reflects the influence of population density;

K_j^1 and K_j^2 are the weighting factors and can be determined by the following equation:

Equation (4) $$K_j^1 = \frac{P_j}{P_T}\text{;}\quad K_j^2 = \frac{l_j}{l_T}$$

where,

P_j – the population in grid j;
P_T – the population in the whole study area;
l_j – residential road length in grid j， km；
l_T – residential road length in the whole study area， km；

Total mileage traveled by area mobile sources can be estimated by subtracting the mileage traveled by line mobile sources from the total vehicle traveled mileage. The total mileage traveled can be calculated as the sum of the vehicle population and average annual mileage traveled for each vehicle type. In this work, 161 street links were treated as line sources. For area source, Hangzhou's urban area was divided into 756 square grids of each having an area of 1 km^2. The parameter α was assumed to be 0.5 here, considering the private cars population accouα for more than 40% of the total population.

Start Times and Patterns Allocation

Since the information collected from vehicle start patterns survey by questionnaire was limited, the locations where vehicle starts happened can not be identified accurately. In this study, an alternative method was developed to allocate start times and patterns. It was assumed that the soak time distribution of each vehicle category was the same in all street types. The start times can be allocated following Equation (5).

Equation (5) $$S_{ij} = \frac{M_{ij}}{M} \times S$$

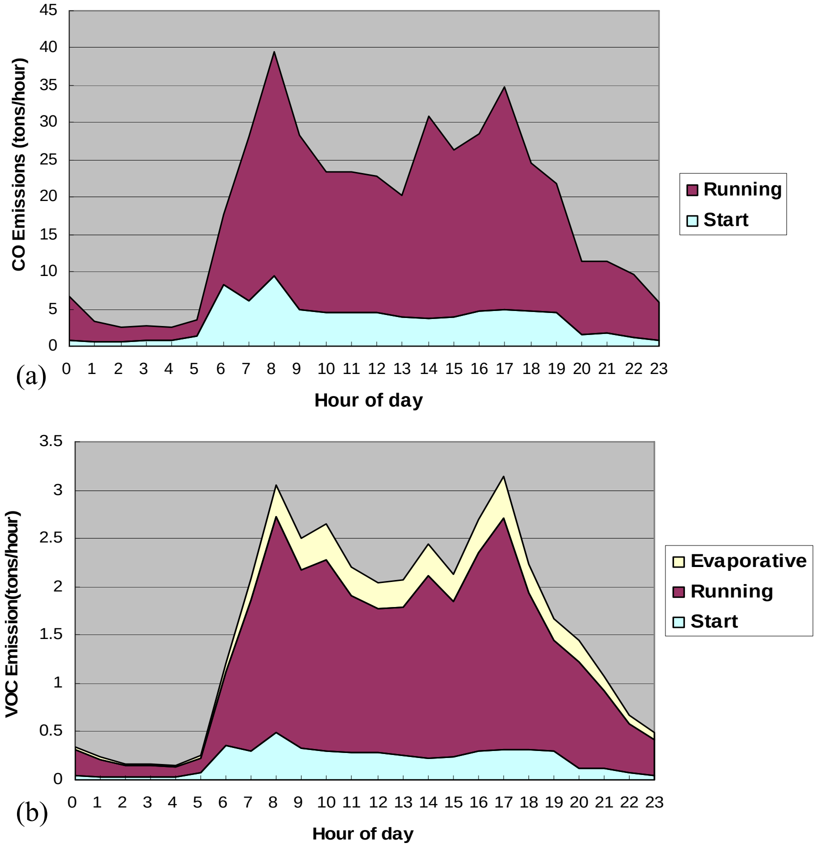
where,

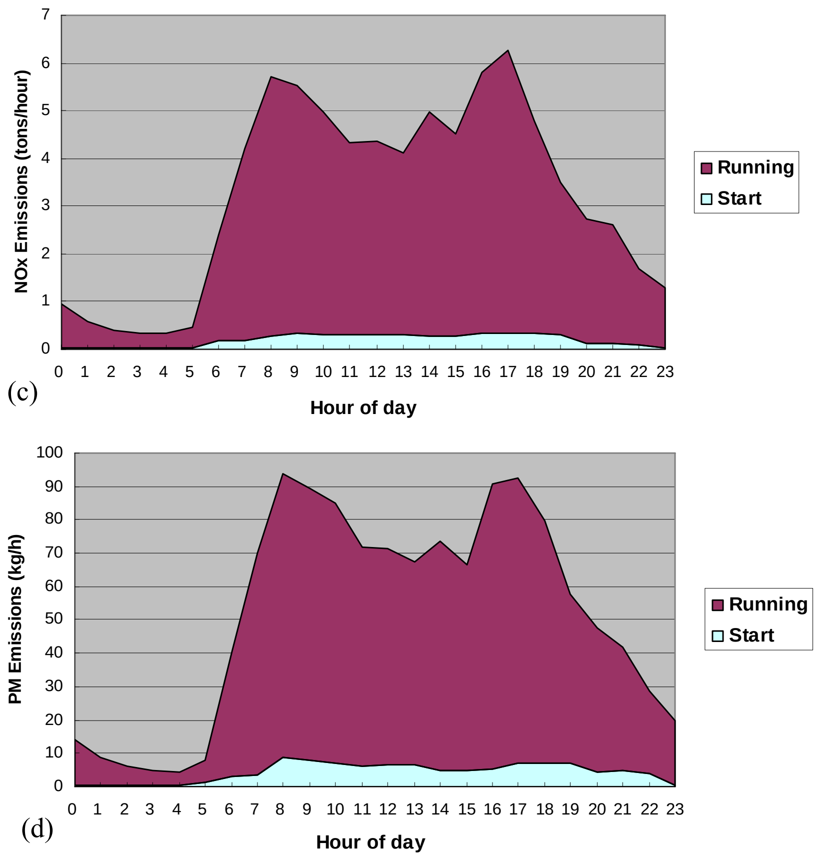
S_{ij} – start times in grid j (or in link j) at i hour, times;
M_{ij} – mileage traveled in grid j (or in link j) at i hour, km ;
M– daily total mileage traveled in the whole study area, km;
S– daily total start times in the whole study area, times;

Temporal Distribution of Vehicle Emissions

For air dispersion modeling, hourly mobile source emission inventories are required to be developed. In previous studies, time variation of vehicle emissions was usually determined by time intensity of traffic flow. Actually, emission factors vary a lot with time. Different from previous studies, hourly emission factor were calculated using IVE model and were combined with hourly VKT and start times to develop hourly emission inventories. Figure 6 shows the daily variation of CO, HC, NO_x and PM_{10} emissions from on-road transportation in Hanghzhou.

Figure 6. Daily temporal distribution of motor vehicle emissions in Hangzhou in 2004

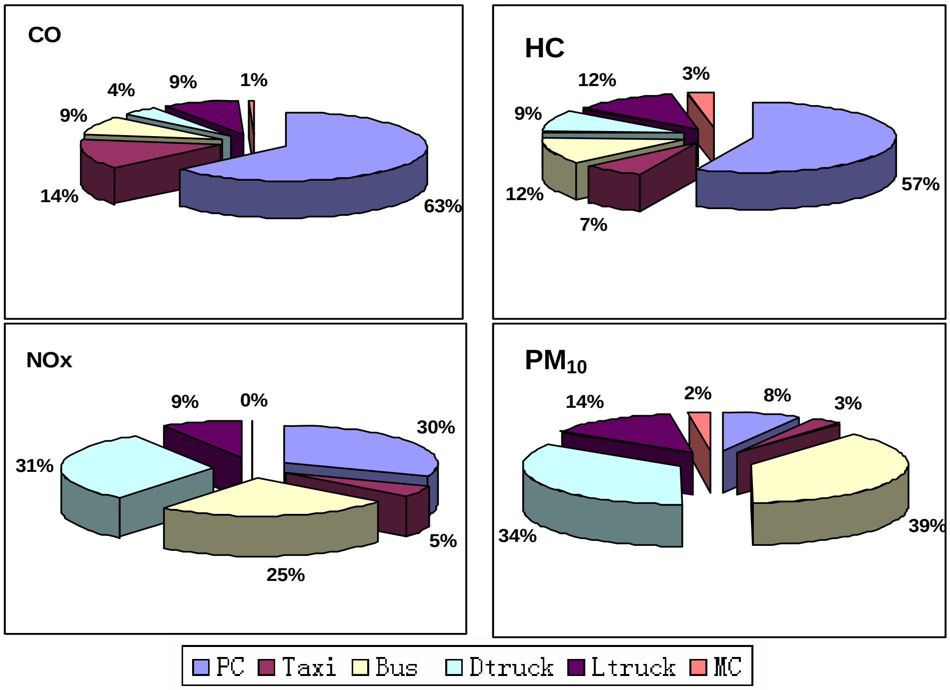




Emission Contribution from Different Vehicle Type

The information of emission contributions from different vehicle types are show in Figure 7. The information is useful for local government regulators to make control policies. It can be found that PC is the most significant contributor of CO and HC emission, while Dtruck and Bus have major influence on NO_x and PM_{10} emissions.

Figure 7. Emission contribution of critical pollutants from different vehicle types

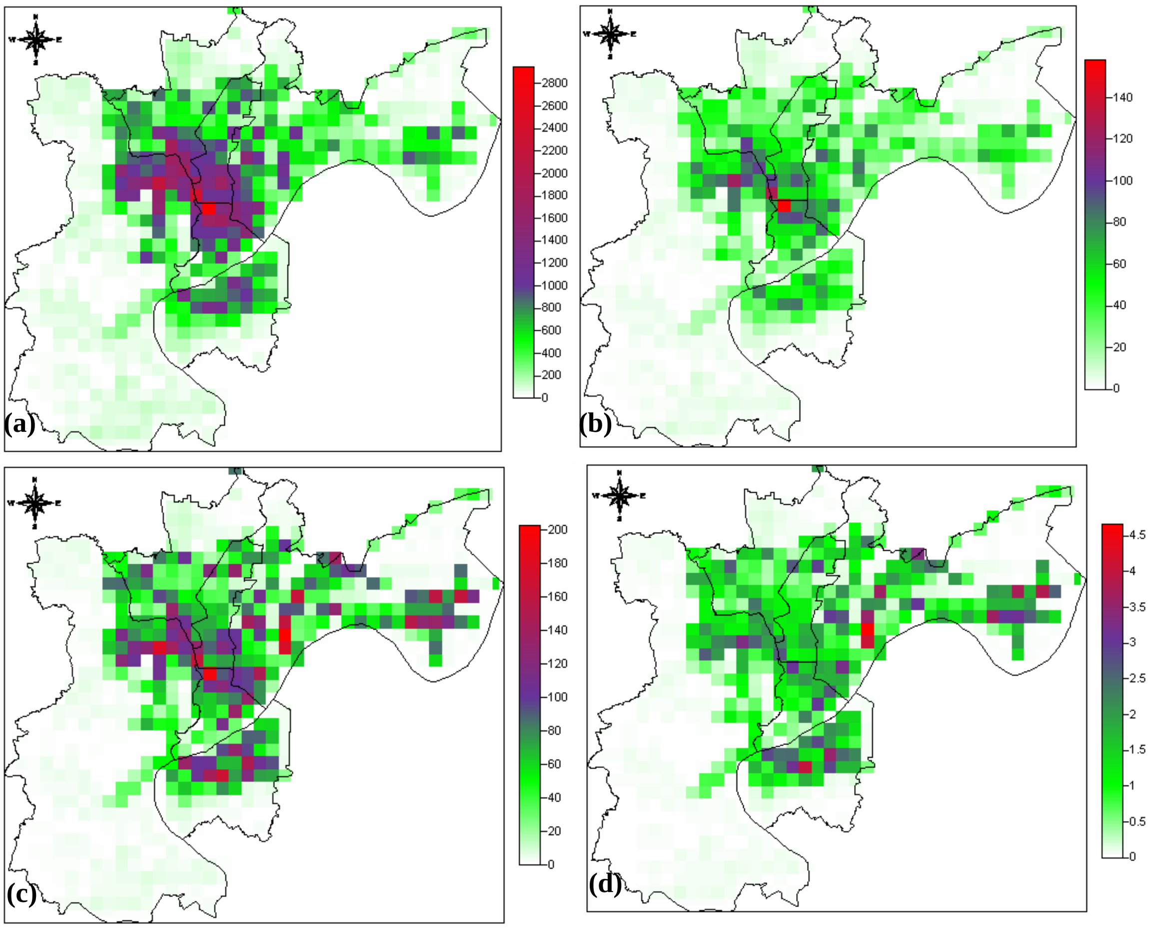


Spatial Distribution of Vehicle Emissions

Based on Hangzhou's GIS system, the high-resolution spatial (1 km×1 km) and temporal (1 hour) emission inventories of CO, HC, NO_x and PM_{10} were established for emission dispersion analysis. Figure 8 shows the spacial distributions of annual vehicle emissions.

It can be observed that, although the spatial distributions trends of the four pollutants' are similar, the high concentrations of CO and HC are more concentrated in the central area than those of NO_x and PM_{10}. This might be explained by the emission contributions of different vehicle types. Because there is a rule in Hangzhou to limit the travel time of Dtrucks in central area, Dtrucks are usually observed in the outer part of the urban area. Overall, Dtrucks are one of major contributors of NO_x and PM_{10} emissions, whose contribution increases the emission amounts of the two pollutants in the outer part of the city.

Figure 8. Spatial distribution of vehicle emissions in Hangzhou in 2004 (t/yr)
(a) CO (b) HC (c) NO_x (d) PM_{10}



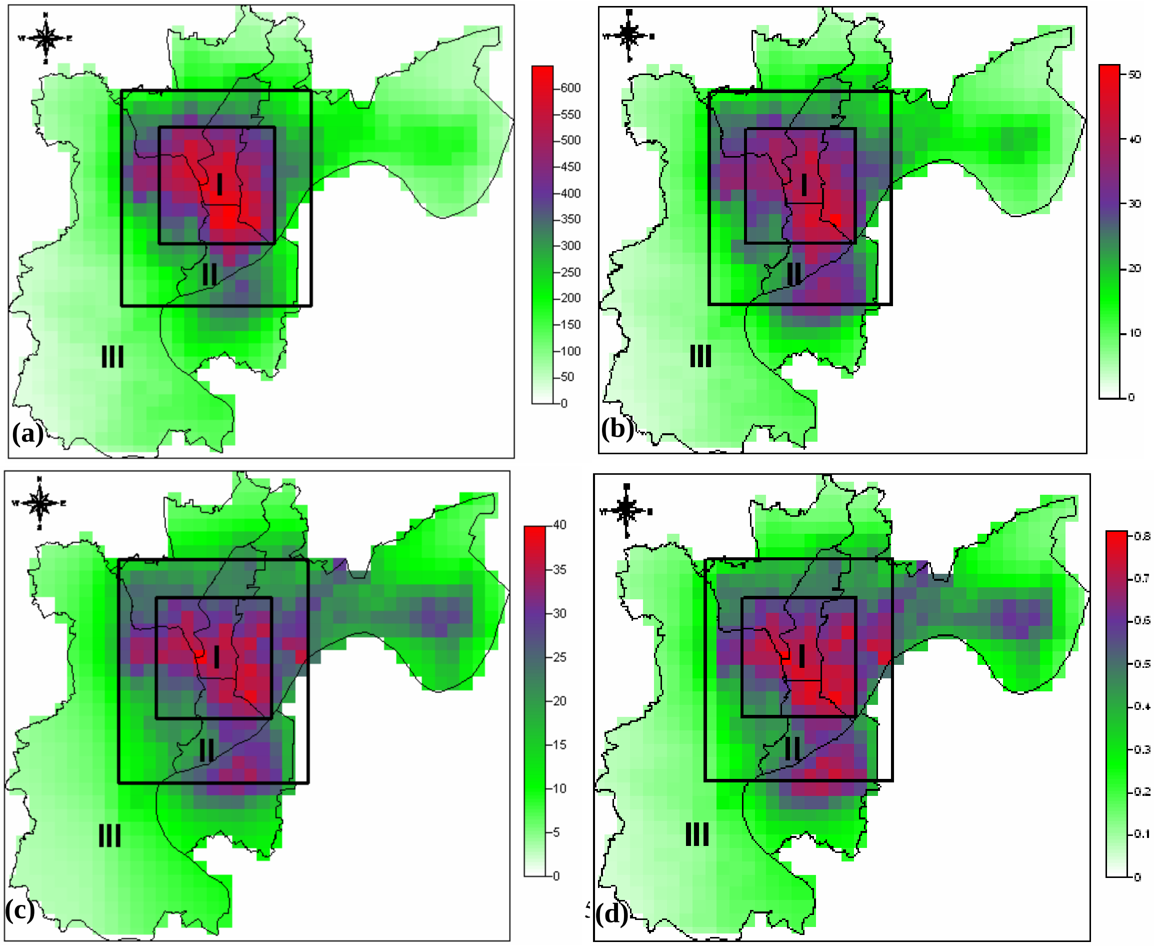
Simulation of the Pollutant Dispersion

USEPA's AERMOD model is a well accepted air pollution dispersion model worldwide. Currently, AERMOD is proposed by SEPA to be one of the regulatory models for the Environment Impact Analyses (EIA) in China. In this study, AERMOD model (version 07026) was adopted to simulate pollutants dispersion caused by motor vehicle emissions. The meteorological data in Hangzhou in 2004 from National Climate Data Center (NCDC) and Hangzhou's Digital Elevation Model (DEM) data with precision of 90 meters were used.

It should be mentioned that since the AEMOD is developed for the U.S., there are some limitations in dealing with meteorological and terrain data when it is used in China. Firstly, when dealing with meteorological data in AERMET, upper air data in China can not be used directly. The upper air data at 0:00 and 12:00 (Chinese local time) should be artificially switched in order for the AEARMET program to recognize the meteorological conditions at sunrise. Secondly, AERMAP (USEPA version) can only deal with DEM data from the Western Hemisphere. To solve this problem, Trinity Consultant's commercial AERMOD software, called BREEZE AERMOD was used in this study. USEPA's AERMAP module has been adjusted in BREEZE AERMOD software and can be used to deal with terrain data from Northern Hemisphere. However, for the area which belongs to neither Western nor Northern Hemisphere, its terrain data can not be dealt correctly by AERMAP module.

The modeling results are shown in Figure 9. Comparing with Figure 8, it can be found that the spatial distributions of the four pollutants' concentrations are similar with the spatial distributions of their emissions. This is consistent with the fact that vehicular emissions usually affect their surrounding area, without considering the chemical reactions. It can also be observed that the annual concentrations of CO caused by on-road transportation are considerablely high (the highest concentration is above 600μg/m^3), while the concentrations of PM_{10} caused by vehicular emissions are low (the highest concentration is about 0.8 μg/m^3). According to the Ambient Air Quality Standards in China, the secondary annual PM_{10} concentration standard is 100 μg/m^3. Considering the annual PM_{10} concentration has exceeded the secondary standard for the past several years, it is believed that motor vehicles are not a major contributor of PM_{10} emissions in Hangzhou. Of course, the accurate estimation of concentration contributions from mobile source depends on the accurate estimation of other sources' emission inventories, mainly the stationary source.

Figure 9. Spatial distribution of annual-averaged emission concentrations caused by motor vehicles in Hangzhou in 2004 (μg/m^3) (a) CO (b) HC (c) NO_x (d) PM_{10}



CONCLUSION

This paper presents a methodology to develop high-resolution temporal and spatial emission inventories from on-road vehicular emissions based on limited database in China for city-level air quality modeling. Hourly emission factors were used instead of time independent emission factors to improve emission inventories. A case study in Hangzhou shows that this method can provide reasonable estimations of pollutant impacts, and provides a scientific tool for use in the control strategies analyses and policy making.

However, the following additional work still needs to be done to improve the accuracy of motor vehicle emission inventories in China.

1. It is important to develop informative and detailed vehicle registration systems in Chinese cities, which may largely reduce the survey efforts and uncertainties in vehicle activity data.
2. The different vehicle travel characteristics during weekends and holidays are not considered in this study. Since they account for almost 30% time of a year, the influence can not be ignored.
3. More onroad emission measurements by remote sensing equipment or by PEMS are needed in Chinese cities, which can be used to adjust the original BEFs in IVE model to improve the accuracy of emission factor's estimation.
4. The measurements on start emissions of vehicles in use are quite scarce in China now, and the information of start times and soak time distributions in Chinese cities are insufficient. More studies needs to be conducted to improve understanding of vehicle start emissions.

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KEY WORDS

Emission Inventory

Air Dispersion Modeling

Mobile Source

Emission Factor

China

Vehicle Activity Data