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Vehicle emissions calculation for urban roads based on the Macroscopic Fundamental Diagram method and real-time traffic information

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ABSTRACT

Vehicle emissions calculation methods mostly use ownership information or annual road monitoring data as the activity level to calculate air pollutant emissions, but it is hard to reflect either the emissions intensity under different conditions or the spatiotemporal characteristics in various sections based on such approaches. This paper presents a method based on the Macroscopic Fundamental Diagram and real-time traffic data to calculate vehicle emissions, which could reflect the operation conditions and emission characteristics of vehicles. Following the 'Technical Guide for the Compiling of Road Vehicle Air Pollutant Emissions Inventories', the emissions of three roads with different lane numbers and road grades in Beijing were estimated and verified using this method. Compared with monitoring data, the average deviations of the traffic flow on the Fifth Expressway, Jingfu National Highway, and Jingzhou Provincial Highway were −25.5%, −26.5%, and −13.4%, respectively, and the average deviations of nitrogen oxides emissions were −27.7%, −12.9%, and −12%, respectively. This method showed good application potentials to construct the emissions inventory applied to the block-scale model and analyze the spatiotemporal distribution characteristics of motor vehicle emissions in urban areas.

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Macroscopic Fundamental Diagram; traffic emissions; road type; vehicle type; real-time data

关键词

MFD; 交通态势; 道路类型; 车型; 交通监测数据

基于MFD及实时路况的城市道路机动车排放计算方法

摘要

本文提出了基于交通流宏观基本图 (MFD) 以及实时路况数据的城市道路机动车排放计算方法, 并以环境保护部发布的指导方法为参照, 对所述方法进行了对比验证。以2015年3月北京市五环路高速, 国道京福路, 省道京周路的氮氧化物排放为例, 两种方法计算结果平均偏差分别为 −27.7%, −12.9%, −12.0%。因此, 基于MFD及实时路况数据对交通流量及机动车排放的估算, 可以较好地反映道路机动车的运行情况及排放特征, 在构建应用于街区尺度模型的排放清单, 城市区域道路机动车排放的时空分布特征等方面具有非常好的应用潜力。

1. Introduction

Road motor vehicle emissions are one of the most important sources of air pollution. The results of source apportionment of atmospheric particulates in 15 cities including Beijing and Shanghai suggested that the contribution of mobile sources to PM_{2.5} (particulate matter with a diameter of less than 2.5 μm) concentrations in local emission sources was ranging from 13.5% to 52.1% (MEEPRC 2018). In order to specify current situations and characteristics of road vehicle emissions, researchers around the world have applied lots of effort in vehicle emissions studies. Zheng, Che, and Wang (2009) proposed the 'spatial allocation method' of regional vehicle pollutant emissions based on traffic flow and 'standard road length' of the road network. Wu et al. (2016)

estimated China's motor vehicle emissions from 1980 to 2013. Wang et al. (2017) estimated the road vehicle exhaust emissions characteristics of the national highways and provincial highways in 2015 using the average annual monitoring data from traffic monitoring stations. Wang et al. (2010) analyzed the emissions inventory for motor vehicles in Beijing, Shanghai, and Guangzhou from 1995 to 2009 using the Computer Programme to Calculate Emissions from Road Transport (COPERT) model. Fan et al. (2015) estimated the road emissions characteristics in Beijing by investigating the composition of vehicle types and their driving conditions using the COPERT model.

Most studies take the motor vehicles as the subjects, and the ownership or average annual road monitoring data as the activity level in their calculations of

atmospheric pollutant emissions, but this is unable to reflect the spatial and temporal characteristics of the motor vehicle emissions in each section, nor can it present the characteristics of the emissions intensity under different traffic conditions. The operation state of road motor vehicles varies greatly due to traffic flow directions and peak hours, which leads to large variations in their emissions. Different emission correction factors were prescribed with different vehicle models in the 'Technical Guide for the Compiling of Road Vehicle Air Pollutant Emissions Inventories' (MEEPRC 2015). Various tools such as the COPERT model, MOVES (Motor Vehicle Emission Simulator) model and IVE (International Vehicle Emissions) model have been developed and modified to adjust these emission factors under different traffic conditions. As a main aspect, the speed of the vehicle was proven to have significant influence on the emission factors (USEPA 2002; Sun 2013). When driving at low speeds ($< 30 \text{ km h}^{-1}$), vehicle emission factors are relatively high due to low engine load and unstable combustion. When driving at moderate or high speeds, the combustion conditions of the engine improves, thus lowering the emission factors (Ma, Zhao, and Liang 2010).

With the increase in environmental management requirements and technology developments, calculation methods are expected to be able to estimate vehicle emissions based on a single road, and to further determine their contributions to the generation of $\text{PM}_{2.5}$ and ozone (Kim et al. 2017). Therefore, real-time road emission characteristics are significant for the presentation of emissions estimates. In the present work, taking Beijing as an example, we generated estimated reference data using real-time readouts from traffic-flow observation stations on 1 March 2018. We chose the Fifth Expressway, Jingfu National Highway, and Jingzhou Provincial Highway as research subjects, each with different lane numbers and road grades, to construct a calculation method for vehicle emissions based on the Macroscopic Fundamental Diagram (MFD) method and real-time road conditions. By comparing with the emissions values obtained from monitoring data, the method was verified with average deviations lower than 30%.

2. Research methodology

2.1. Calculation method

Monitoring data on the expressway, national highway, and provincial highway were chosen to build and verify our method. The multi-scale emissions of road vehicles were estimated by using the method proposed in the

'Technical Guide for the Compiling of Road Vehicle Air Pollutant Emissions Inventories' (MEEPRC 2015). An average flow-average velocity model was established based on the MFD descriptions of flow, speed, and density. The activity levels of road motor vehicles were obtained from the average traffic flow in each section by analyzing average speeds in real-time road conditions. The traffic situations in Beijing on 1 March 2018 and in March 2015 were obtained through the Gaode Maps application programming interface (API) to calculate the emissions from the Fifth Expressway, Jingfu National Highway, and Jingzhou Provincial Highway separately.

2.1.1. MFD and real-time road conditions data

The MFD method was proposed by Geroliminis and Daganzo (2008) to reflect the correlations among traffic parameters of flow, speed, and density (Geroliminis and Daganzo 2008; Yue 2015):

$$\begin{cases} q^u = \frac{1}{N} \sum_i q_i \\ k^u = \frac{1}{N} \sum_i k_i, \\ v^u = q^u / k^u \end{cases} \quad (1)$$

where q^u , k^u , and v^u are the average traffic flow, average density, and average speed of the road network, respectively; N is the total number of sections; and i is the section ID. The method has been widely used in the dynamic division of small areas and traffic density prediction (Ma and Liao 2014; Gayah and Dixit 2013). Gayah and Dixit (2013) used MFDs to predict the real-time network traffic density with floating car data. With less data and simple calculation, the MFD approach gave them promising results with high accuracy.

Real-time road traffic data are multi-dimensional spatial data obtained by vehicle locations and road monitoring equipment. They can reflect the operation states of the traffic network in real time, including road traffic speed and the degree of congestion. Typical data, such as probe vehicle data and traffic situation data, can be obtained through the API of electronic maps, such as Gaode Maps (Zhang et al. 2017; Dong et al. 2014). The real-time road condition data contain real-time speed information in different sections, which can be used in the calculation of road vehicle emissions.

2.1.2. Calculation method of exhaust emission from road vehicles

The exhaust emissions from road vehicles were calculated as follows:

$$E = Q \times EF \times L \times R \times 31 \times 24 \times 10^{-6}, \quad (2)$$

where E is the monthly emissions of CO (carbon monoxide), NO_x (nitrogen oxides), $\text{PM}_{2.5}$, and PM_{10} (particulate matter with a diameter of less than $10 \text{ }\mu\text{m}$) from

different motor vehicle emission sources (units: tons); Q refers to the average flow rate of one-lane motor vehicles (units: vehicles per hour); EF is the comprehensive emissions factor of the pollutants in exhaust emissions per unit distance of a vehicle (units: g km^{-1}); L is the driving distance of a vehicle on the road (units: km/vehicle); and R is the reduction coefficient of the road.

The integrated emissions factor, EF , is a comprehensive factor that includes the proportion of different vehicles and the emissions factor under certain conditions:

$$EF_{ij,t} = \sum_z^{n_z} EF_{j,z} \times P_{i,z} \times J_{ij,z,t}, \quad (3)$$

where i is the section number, j is the pollutant type, t is the time, and z is the motor vehicle type. Therefore, $EF_{ij,t}$ is the comprehensive emissions factor of a pollutant at a certain time in a certain section; $P_{i,z}$ is the proportion of a motor vehicle type in section i ; $J_{ij,z,t}$ is the reference emissions factor correction coefficient of a certain vehicle type in a certain section at time t , which can be obtained through the vehicle emissions model or other correction functions; and n_z is the number of the vehicle type z .

In the case of multi-lane driving, motor vehicle traffic behaviors in the same direction will influence each other, thus affecting the traffic capacity of adjacent lanes. Therefore, the calculation of emissions was conducted by replacing the number of lanes with the reduction coefficient of the road R (Zhang et al. 2015). When the number of lanes was 1, 2, 3, 4, and 5, the corresponding lane conversion factors were 1.00, 1.87, 2.65, 3.20, and 3.65, respectively.

2.1.3. Average flow–average velocity model

Common models describing the relationships between average flow and average velocity include linear models, exponential models, and logarithmic models, among which the Underwood Index Model fits well with both low, medium, and high-density data and the measured data (Yue 2015). By using this model, an average flow–average velocity model was established as follows:

$$q^u = -\rho_{\max} v \ln \frac{v}{v_f}, \quad (4)$$

where q^u is the average traffic flow (units: $\text{pcu (passenger car unit) h}^{-1}/\text{lane}$); v is the average vehicle speed (units: km h^{-1}); v_f refers to the driving speed without mutual interference between vehicles or influence of traffic conditions (units: km h^{-1}); and ρ_{\max} is the density corresponding to the maximum traffic flow, also known as the optimal density (units: $\text{pcu km}^{-1}/\text{lane}$), which is deduced as follows (Sun 2013):

$$\rho_{\max} = \frac{q_c^e}{v_f}, \quad (5)$$

where q_c is the traffic flow, which refers to the maximum number of vehicles that can pass through a certain section per unit time (units: pcu h^{-1}). The road design capacity of different grades is listed in Table 1.

The conversion of traffic flow q used small passenger cars as the standard model. Different types of vehicles on different roads are different. For example, the proportion of medium and small passenger cars on expressways is about 62%–67%, and that of national and provincial medium and small passenger cars is about 47%–49% (Wang et al. 2017). Different vehicle models have different emission factors. Therefore, the traffic flow of different roads should be converted according to vehicle types in the calculation. The conversion coefficients corresponding to passenger cars, large buses, large freight cars, and articulated vehicles are 1.0, 2.0, 2.5, and 3.0, respectively (MOHURD 2012).

2.2. Data sources

Real-time traffic data in Beijing on 1 March 2018 were obtained through the Gaode Open Platform (<http://lbs.amap.com/>), as shown in Figure 1. The daily average data in Beijing obtained by traffic flow monitoring stations in March 2015 were used as the activity-level data for verification. Relative information of the Fifth Expressway, Jingfu National Highway, and Jingzhou Provincial Highway were extracted from the traffic network data.

As the emission factors of different vehicle types are different, it is important to determine the proportion of vehicle types on different roads. In this study, we analyzed the monitoring data of the Fifth Expressway, Jingfu National Highway, and Jingzhou Provincial Highway in March to obtain the proportion of different road types. With this proportion as the weight, the emission factors under different speed ranges on each road were

Table 1. Road design capacity of different grades (MOT 2003).

Highway grade	Design speed (km h^{-1})	Design capacity ($\text{pcu h}^{-1}/\text{lane}$)
Expressway	120	1600
	100	1400
	80	1200
First-class highway	100	1400
	80	1200
	60	900
Second-class highway	80	550–1600
	60	
	40	
Tertiary highway	40	400–700
	30	
Fourth-class road	20	< 400

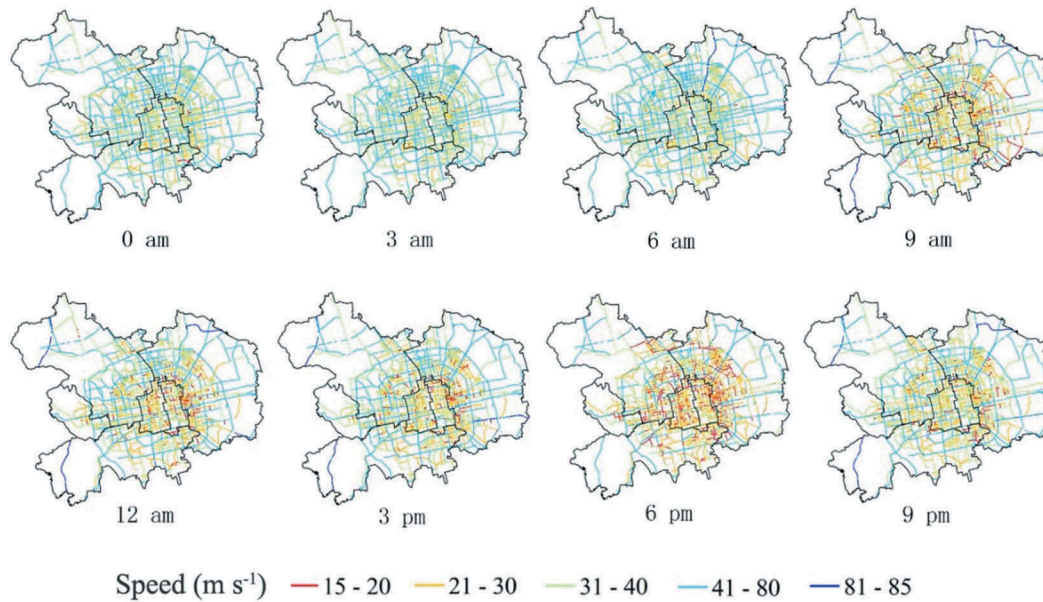


Figure 1. Hourly traffic conditions in the Beijing urban area at local standard time.

obtained according to the guidance method in the 'Technical Guide for the Compiling of Road Vehicle Air Pollutant Emissions Inventories', as shown in Table 2.

Free flow velocity, optimal density, and capacity are the basic parameters to calculate the average flow–average velocity model in the MFD (Equation (4)). Yue (2015) constructed the characteristic parameter values of road traffic flow at all road levels (expressways, trunk roads, sub-branch roads) in Beijing through statistical analysis. In our study, the basic parameters of the Fifth Expressway, Jingfu National Highway, and Jingzhou Provincial Highway were modified according to the design capacity of different grades of road (Table 1), the speed limit regulation of specific roads, the number of lanes, etc. (Table 3).

Table 2. Emission factors of pollutants from different roads under different traffic conditions.

Road name	Speed (km h ⁻¹)	Emission factors of pollutants (g km ⁻¹)			
		CO	NO _x	PM _{2.5}	PM ₁₀
Fifth Expressway	> 80	1.61	1.70	0.07	0.08
	40–80	1.33	1.91	0.08	0.09
Jingfu National Highway	40–80	1.24	1.52	0.07	0.07
	30–40	2.22	1.80	0.12	0.14
	20–30	3.22	2.19	0.18	0.20
Jingzhou Provincial Highway	< 20	4.20	2.68	0.23	0.26
	40–80	1.17	1.58	0.07	0.08
	30–40	2.15	1.82	0.13	0.14
	20–30	3.04	2.29	0.19	0.21
	< 20	3.95	2.80	0.25	0.27

Table 3. Basic MFD parameters for each road.

Parameter	Fifth Expressway	Jingfu National Highway	Jingzhou Provincial Highway
Free-flow speed (km h ⁻¹)	100	50	60
Optimum density (pcu km ⁻¹ /lane)	38	43.3	31
Traffic capacity (pcu h ⁻¹ /lane)	1400	800	700

3. Results and discussion

3.1. Estimation of road traffic flow

Based on the speed data in the real-time road conditions data, the average traffic flow on each road at different times was estimated with the road grade, number of lanes, and by using the average speed–average flow model. The results reflected well the changes in traffic flow during the morning and evening peaks, as shown in Figure 2.

The deviation between the estimated average daily traffic flow value and measured value on Jingzhou Provincial Highway was less than 15%, as presented in Table 4. The deviations between the estimated values and the measured values on the Fifth Expressway and Jingfu National Highway were all above 25%, which might be related to the calculation defects, the uncertainty of the selected parameters, and the difference between data collection years. As the speed limits in different sections are different and vary regularly, errors could be generated as well. Besides, setting the free-flow velocity as a uniform value might introduce some errors.

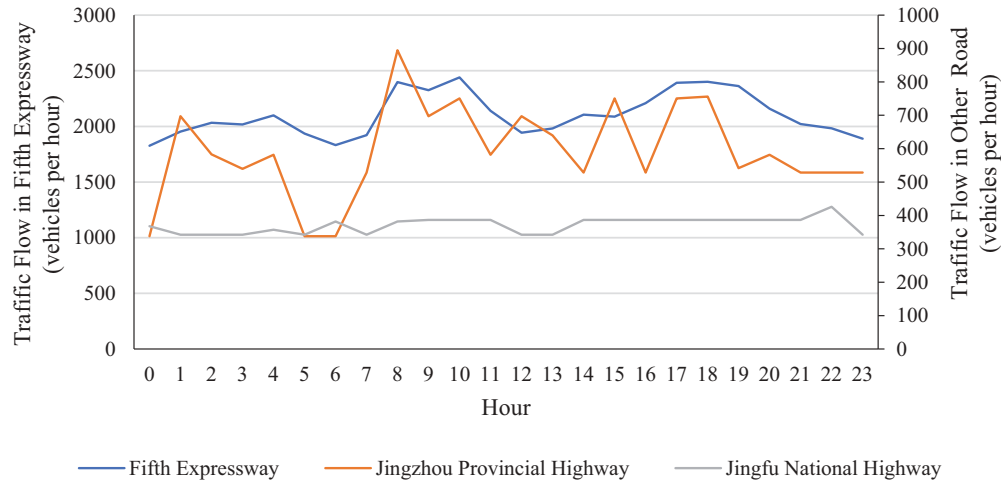


Figure 2. Hourly traffic flow estimated by the MFD method on different roads.

Table 4. Comparison between the estimated traffic flow with the MFD method and the measured traffic flow.

Road	Estimate	Traffic flow (cars d ⁻¹)		
		Range of measured values*	Measured mean	Relative deviation
Fifth Expressway	90,511	118,777–134,110	121,526	–25.5%
Jingfu National Highway	14,947	15,107–25,522	20,335	–26.5%
Jingzhou Provincial Highway	25,048	24,617–34,087	28,939	–13.4%

*Refers to the average daily measured value of the road in March 2015.

However, the estimation of traffic flow based on the MFD method reflects well the real-time status of traffic operations by discriminating different lane numbers and road grades.

3.2. Estimation of monthly average road emissions

The traffic flow and integrated emission factors under different operating conditions were estimated by the MFD method, as shown in Table 2. According to the exhaust emissions of road vehicles (Equation (2)), the emissions of road vehicles at different times on each road were estimated and compared with the monthly average emissions calculated by actual monitoring flow (Table 5). It was observed that deviations between the estimated monthly average emissions calculated by the MFD method and the measured emissions on Jingzhou Provincial Highway and Jingfu National Highway were around 10%, while for the Fifth Expressway the deviation was around 25%. The estimation of the traffic flow could lead to these deviations of the calculated average traffic flow, and further influence the

Table 5. Comparison between the estimated monthly emissions with the MFD method and the measured emissions.

Road	Method	Average monthly emissions (tons)			
		CO	NO _x	PM _{2.5}	PM ₁₀
Fifth Expressway	MFD method	407	404	17	19
	Actual flow method	553	559	23	26
	Deviation	–26.3%	–27.7%	–25.7%	–26.2%
Jingfu National Highway	MFD method	10.2	12.3	0.5	0.6
	Actual flow method	10.6	14.1	0.6	0.7
	Deviation	–3.3%	–12.8%	–10.5%	–10.9%
Jingzhou Provincial Highway	MFD method	16	22	1.0	1.1
	Actual flow method	19	25	1.1	1.2
	Deviation	–12.6%	–12.0%	–10.5%	–10.8%

accuracy of the estimated monthly emissions as mentioned above. In addition, despite assuming all the motor vehicle speeds in different sections to be the same, when calculating estimated emissions, different emission factors were applied based on different sections, which also led to certain deviations.

Although in the estimation of traffic flow the deviations between the Fifth Expressway and Jingfu National Highway were at similar levels, the emission calculation result of Jingfu National Highway was significantly smaller than that of the Fifth Expressway. The main reason was that the speed of the traffic flow on Jingfu National Highway fluctuated significantly along the variation of the traffic demand, which led to relatively large differences in emission factors in different sections at different time (Table 2). However, the changes in traffic flow speed for the Fifth Expressway were small, which led to relatively small variations of emission factors in different

sections at different times. Overall, the deviations among emissions estimations were mainly related to the difference in estimated traffic flow.

3.3. Spatial and temporal emission characteristics of road vehicles

NO_x is a typical gaseous pollutant generated by road motor vehicles. In this study, we took NO_x emissions along the Fifth Expressway as an example to study the spatial and temporal emission characteristics reflected by the MFD estimation method. The emissions of NO_x at 0000 LST and 1200 LST (as the traffic troughs), as well as at 0900 LST and 1800 LST (as the traffic peaks), were compared, as shown in Figure 3. Combined with Figure 2, it can be seen that the overall emissions during the morning peak (0900 LST) and evening peak (1800 LST) were much higher than those at 0000 LST and 1200 LST. The highest nitrogen oxide emissions were found in the northeastern part of the city and the intersections. The overall NO_x emissions at 0000 LST and 1200 LST were relatively low, which were mainly generated in traffic hubs. In addition, the emissions from the intersections on the Fifth Expressway and the Jingkai Highway were consistently high at each time period.

By comparing the hourly results of the average $\text{PM}_{2.5}$ concentration data in March 2018 from traffic environmental monitoring stations and non-traffic environmental monitoring stations in Beijing, it was found that $\text{PM}_{2.5}$ concentrations had a significant peak at traffic monitoring stations at night. The highest estimated hourly emissions of $\text{PM}_{2.5}$ were found on the Fifth Expressway as it is the main expressway in Beijing with heavy traffic flow, and the lowest was found on Jingfu National Highway, as shown in Figure 4(a). The emissions of $\text{PM}_{2.5}$ on Jingzhou Provincial Highway were about 40% higher than on Jingfu National Highway. The Fifth Expressway and Jingzhou Provincial Highway showed similarly small peaks of $\text{PM}_{2.5}$ emissions from 0000 LST to 1800 LST, which could be related to higher $\text{PM}_{2.5}$ concentrations monitored at traffic stations, as shown in Figure 4(b). Such results imply that trucks running at night in Beijing could be one of the main sources of $\text{PM}_{2.5}$ emissions.

4. Conclusions

The estimated vehicle traffic flow and emission results based on the MFD method and real-time road conditions data were close to the measured results. Compared with

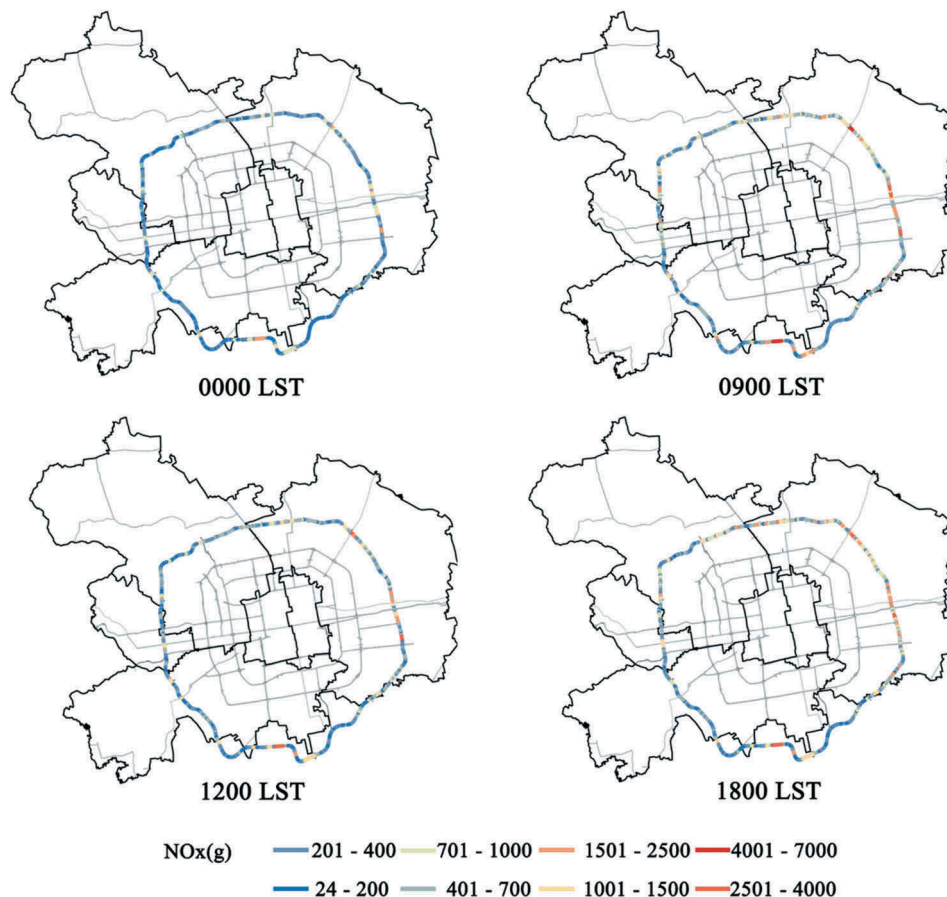


Figure 3. Temporal variation of NO_x emissions in the Fifth Expressway at local standard time.

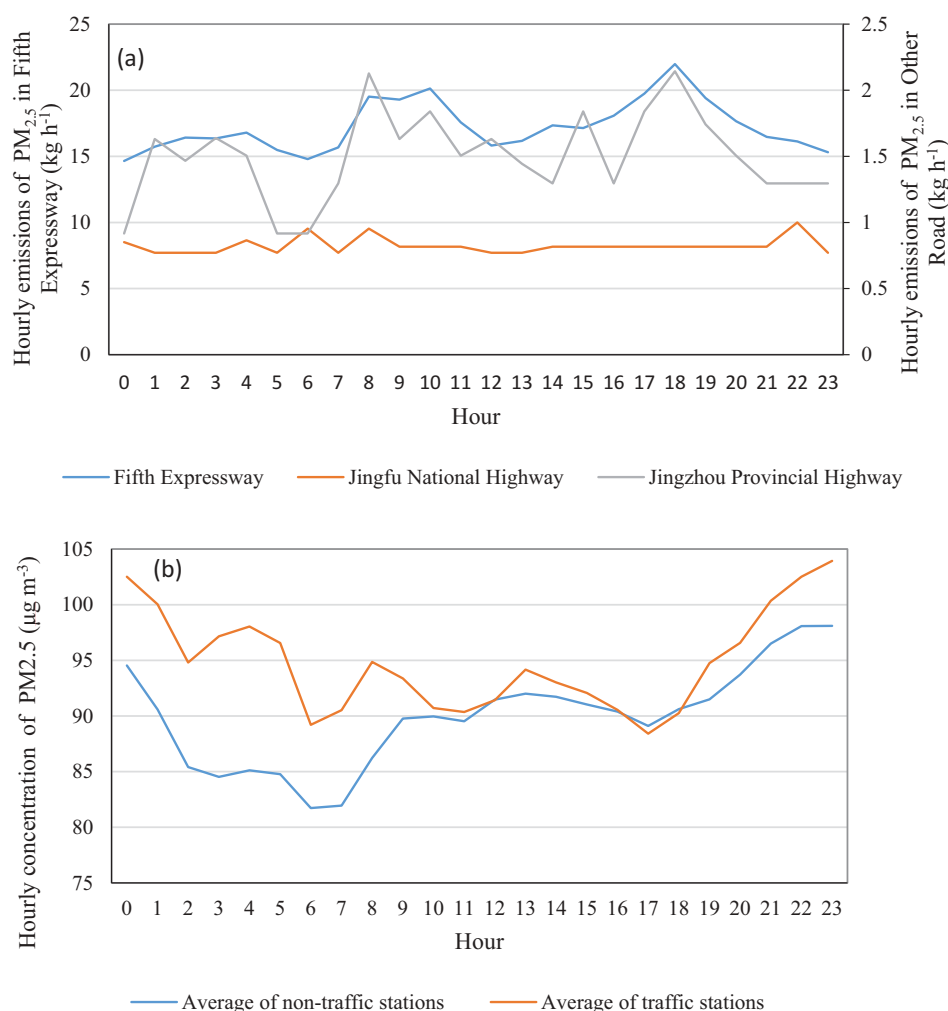


Figure 4. Estimated hourly (a) emissions of PM_{2.5} on the Fifth Expressway, Jingfu National Highway, and Jingzhou Provincial Highway and (b) average concentrations of PM_{2.5} at non-traffic monitoring stations and traffic monitoring stations.

monitoring data in March 2015, the average deviations of the traffic flow on the Fifth Expressway, Jingfu National Highway, and Jingzhou Provincial Highway were −25.5%, −26.5%, and −13.4% respectively, and the average deviations of NO_x emissions were −27.7%, −12.9%, and −12%, respectively.

In this study, the inaccuracy of the traffic flow estimation based on the MFD and real-time road conditions data was mainly due to the following reasons: (1) the uncertainty of free-flow speed and optimal density parameters in basic parameters of the MFD; (2) the uncertainty of real-time road conditions data and road network information. Also, the inaccuracy of the traffic emissions calculation was mainly because of the uncertainty in the vehicle type distribution, emission factors, traffic flow, and operation conditions.

This method based on the MFD and real-time traffic data can reflect the operation conditions and emission characteristics of vehicles. The method shows promising application potential in the construction of emissions inventories as applied to block-scale models and analysis of the spatiotemporal distribution characteristics of motor vehicle emissions in urban areas.

Disclosure statement

No potential conflict of interest was reported by the authors.

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References

- Dong, Z., Q. Zhou, S. Chen, R. Hu, Y. Wang, and Y. Wu. 2014. "Evaluation Method of Urban Traffic Congestion Based on Trace." (In Chinese). *China's Annual Meeting on Intelligent Transportation*. doi:U491.265.
- Fan, S., L. Tian, D. Zhang, and S. Qu. 2015. "Emission Characteristics of Vehicle Exhaust in Beijing Based on Actual Traffic Flow Information." (In Chinese) *Environmental Science*, no. 8: 2750–2757. doi:10.13227/j.hjx.2015.08.004.
- Gayah, V., and V. Dixit. 2013. "Using Mobile Probe Data and the Macroscopic Fundamental Diagram to Estimate Network Densities." *Transportation Research Record Journal of the Transportation Research Board* 2390 (–1): 76–86. doi:10.3141/2390-09.
- Geroliminis, N., and C. F. Daganzo. 2008. "Existence of Urban-scale Macroscopic Fundamental Diagrams: Some Experimental Findings." *Transportation Research Part B* 42 (9): 759–770. doi:10.1016/j.trb.2008.02.002.
- Kim, Y., Y. Wu, C. Seigneur, and Y. Roustan. 2017. "Multi-scale Modeling of Urban Air Pollution: Development and Application of a Street-in-Grid Model by Coupling MUNICH and Polair3D." *Geoscientific Model Development Discussions* 1–24. doi:10.5194/gmd-2017-189.
- Ma, D., Y. Zhao, and B. Liang. 2010. "Study on Emission Characteristics of Light Vehicles under Different Driving Conditions." (In Chinese). *Beijing Automotive Engineering*. doi:10.3969/j.issn.1002-4581.2010.04.003.
- Ma, W., and D. Liao. 2014. "Progress and Prospects of Macroscopic Fundamental Diagram (In Chinese)." *Journal of Wuhan University of Technology (Transportation Science & Engineering)* 38 (6): 1226–1233. doi:10.3963/j.issn.2095-3844.2014.06.010.
- MEEPRC (Ministry of Ecological Environment of the People's Republic of China) 2015. "Technical Guide for Compiling the List of Air Pollutants Discharged by Road Vehicles (Trial) (In Chinese)." <http://www.zhb.gov.cn/gkml/hbb/bgg/201501/>
- MEEPRC (Ministry of Ecological Environment of the People's Republic of China). 2018. "Annual Report on Environmental Management of Motor Vehicles in China (2018)." (In Chinese). <http://dqhj.mee.gov.cn/jdchjgl/zhgltd/201806/>
- MOHURD (Ministry of housing and urban-rural development of the People's Republic of China) 2012. "Code for Design of Urban Road Engineering." (In Chinese).
- MOT (Ministry of Transport of the People's Republic of China). 2003. "Technical Standard of Highway Engineering". (In Chinese).
- Sun, G. J. 2013. "Characteristics and Countermeasures of PM_{2.5} And NO_x Emission from Motor Vehicles." (In Chinese). Doctoral Thesis, Zhejiang University. doi:10.1094/PDIS-02-13-0213-PDN.
- USEPA (United States Environmental Protection Agency). 2002. "User's Guide to MOBILE6.0." *Mobile Source Emission Factor Model*: 420–422.
- Wang, H., L. Fu, Y. Zhou, X. Du, and W. Ge. 2010. "Trends in Vehicular Emissions in China's Mega Cities from 1995 to 2005." *Environmental Pollution* 158 (2): 394–400. doi:10.1016/j.envpol.2009.09.002.
- Wang, R., K. Wang, F. Zhang, J. Gao, Y. Li, and T. Yue. 2017. "Emission Characteristics of Vehicles from National Roads and Provincial Roads in China." (In Chinese). *Environmental Science* 38 (9): 3553–3560. doi:10.13227/j.hjx.201701087.
- Wu, X., Y. Wu, S. Zhang, H. Liu, L. Fu, and J. Hao. 2016. "Assessment of Vehicle Emission Programs in China during 1998–2013: Achievement, Challenges and Implications." *Environmental Pollution* 214: 556–567. doi:10.1016/j.envpol.2016.04.042.
- Yue, Y. Y. 2015. "Multi-level Fundamental Diagram of Traffic Flow for Beijing Based on Multi-Source Data." (In Chinese). Master Thesis, Beijing Jiaotong University.
- Zhang, T., L. Sun, Y. Huang, L. Zhou, and W. Zeng. 2017. "Relationship between Traffic Congestion and Landuse Based Online Data: Taking Tianjin Binhai New Area as an Example (In Chinese)." *Transport Research* 3 (2): 1–8. doi:10.13227/j.hjx.2015.08.004.
- Zhang, X., Z. Fang, Q. Li, and S. Lu. 2015. "A Spatio-temporal Analysis on the Heterogeneous Distribution of Urban Road Network Capacity Based on Floating Car Data." (In Chinese). *Journal of Geo-information Science* 17 (3): 336–343. doi:10.3724/SP.J.1047.2015.00336.
- Zheng, J., W. Che, and Z. Wang. 2009. "Traffic Flow and Road Network-based Spatial Allocation of Regional Mobile Source Emission Inventories." (In Chinese). *Journal of Environmental Science* 29 (4): 815–821. doi:10.13679/j.hkxxb.2009.04.018.