Assessment of Different Methods in Analyzing Motor Vehicle Emission Factors

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Abstract: To explore the emission characteristics of vehicle's pollutants is of great significance to prevent and control the diffusion of pollutants. Limited by geographic location and economic condition, the models- and guidelines-based studies on vehicle's emission factor have become more concerned measures than the actual measurement. By analyzing the actual operating conditions of motor vehicles, this study obtain the emission factors of typical pollutants from different motor vehicles by adopting international vehicle emission (IVE) model and guideline method, respectively. Furthermore, the resulting emission factors by the above methods were compared and analyzed with on-road method. The results show that: (1) the emission factors of vehicle pollutants change regularly with velocity, emission standard and accumulated mileage. Taking CO as an example, its emission factor shows a downward trend with the increase of velocity and emission standard, and an upward trend with the increase of accumulated mileage; (2) Compared with the actual measurement, the vehicle emission factor obtained by the guideline method has a large error, while the IVE model is close to the actual.

Keywords: vehicle emission factors; IVE model; Guideline method; influencing factors; on-road test; comparative analysis

Highlights

- Vehicle emission factors based on the IVE model are established.
- Vehicle emission factors based on the Guide method are established.
- Influencing factors of vehicle emission factors are discussed.
- Vehicle emission factors based on typical three methods are compared.

1. Introduction

Transportation sector has posed various global challenges, including climate change and air pollution (Fan et al., 2018; Song et al., 2019), in rapidly developing countries such as China (Zheng et al., 2017; Adamiec et al., 2016). Chinese urbanization and increasing purchasing power have significantly stimulated the sharp increase in motor vehicle ownership. In 2019, vehicle ownership in China reached 340 million, with an average annual growth rate of 7.9% (MTPRC, 2019). As a result, particulate matter (PM) emitted by motor vehicles in principle cities (such as Beijing, Tianjin and Shanghai) contributed to 13.5%~51.1% of the total PM emissions (BMEEB, 2020; TEEB, 2018; SMEEB, 2020). Carbon monoxide, nitrogen oxides and ammonia emitted by motor vehicles also seriously threaten people's health and safety (Wu et al., 2017; Leung et al., 2000). Therefore, it is of great significance to analyze the emission characteristics of vehicle pollutants to mitigate and manage the diffusion of pollutants.

Current research that analyzes emission characteristics of motor vehicles mainly focused on vehicle emission factors using measurement-based methods and model-based methods (Franco et al., 2013; Nesamani et al., 2010), with the assistance of big data in the latest research (Deng et al., 2020). The measurement-based method involves laboratory test and on-road test. The former mainly uses benchmark tests, and the latter includes tunnel tests, remote sensing and on-vehicle tests (Gao et al., 2019). With the increasing attention to the transient characteristics of emission factor of motor vehicles for actual roads, on-road test has gradually become a research hotspot in recent years. Hu et al. (2012) tested the emission factors of diesel taxis in Macao by using a portable test system and pointed out that better traffic planning was conducive to reducing pollutant emissions. With similar methods, emission factors of passenger cars were developed in Lombardia, Italy (Marina et al., 2013), Shanghai, Beijing and Guangzhou, China (Huo et al., 2012a & 2012b). Westerdahl and Wang (2009; 2010; 2011) analyzed the emission characteristics of Beijing's motor vehicle, whose results implied that traffic control was an effective measure to effectively reduce pollutant emissions. By analyzing $PM_{2.5}$ emission factors of motor vehicles for Hong Kong, Cheng et al. (2010) were skeptical of Westerdahl's comments and pointed out that the test cycle and meteorological changes were not taken into account in Westerdahl's experiment. By establishing a black-box model based on actual measurement, Jamriska et al. (2001) analyzed the emission factors of motor vehicles in Queensland, which were higher than those of the actual emission factors. Other studies (Costagliola et al., 2014; Dong et al., 2014; Mamakos et al., 2013; Zhu et al., 2016; Liu et al., 2019; Ewen et al., 2009; Bhattacharjee et al., 2011) also analyzed emission factors of motor vehicles based on measured method.

The model-based methods involve mathematical models and physical models. At present, MOBILE, COPERT and IVE model are widely used to study emission factors of motor vehicles. The IVE model is widely used because of its strong adaptability in developing countries and regions. For example, Gao et al. (2020) established the vehicle emission inventory of Harbin-Changchun megalopolis by using the IVE model and simulated the emission inventory of different scenarios. The results show that the elimination of old vehicles was the most effective measure to reduce the emission of pollutants. Guo et al. (2007a) conducted a comparative analysis on the vehicle emission factors between IVE model and remote sensing method in a case study of Hangzhou city, and found that emission factors obtained from IVE model were overestimated. Further, they made a fuel-based emission inventory (Guo et al., 2007b). Wang et al. (2008) established the vehicle emission inventory of Shanghai based on IVE model and concluded the error of emission factor obtained by IVE model was within 10% compared with the actual situation. By analyzing vehicle emissions inventory in Tehran, Shafie-Pour et al. (2013) found that fine and reasonable public transport system, land use and urban spatial planning were very important to reduce pollutant emissions in this area.

However, there is a knowledge gap in the comparison of vehicle emission factors obtained by different methods. In addition, there are some deficiencies in the uncertainty analysis. In this paper, Changchun City is selected as a typical city with low temperature for motor vehicles emission factor analysis. Performing the analysis is based on IVE model and the "technical guideline for the preparation of road vehicle air pollutant emission list (hereinafter referred to as the "guideline method"). Furthermore, we analyze the influencing factors of emission factors, and do a comparative analysis.

2. Theory and Methods

2.1 IVE model

The IVE model was developed by the *International Sustainable Systems Research Center* and the *University of California, Riverside* for precisely estimating vehicle emissions, especially in developing countries with various technical parameters (Guo et al., 2007). Compared to MOBILE 6 model, IVE model allows an efficient estimation of vehicle emission factors under various driving conditions (Davis et al., 2005; Rakha et al., 2003).

The IVE model has 1,372 kinds of technical parameters including vehicle type, fuel, engine size, driving mileage, evaporation control and exhaust purification technology, and 45 parameters defined by users themselves (Shafie-Pour et al., 2013). The emission factor Q_t is calculated as follows:

$$Q_t = B_t \prod_x K_{xt} \tag{1}$$

where, Q_t is the calibrated emission factor in start-up and running, g/km; further interpretation as shown in Eq. (2) and Eq. (3). B_t represents the basic emission factor of start-up and operation, g/km. K_{xt} is the correction factor, including local information (e.g. temperature, humidity, altitude, road slope, fuel quality, velocity, mileage, starting times, specific power and hot soak time), fuel quality and driving parameters. Fuel quality and driving parameters vary with vehicle technologies (such as different engine, mileage, exhaust control system, air fuel control system) and various fuels that power the vehicles.

$$Q_{running} = \bar{U}_{FTP} \cdot D / \bar{U}_C \cdot \sum_t [f_t \cdot Q_t \cdot \sum_d (f_{dt} \cdot K_{dt})] \tag{2}$$

$$Q_{\text{start}} = \sum_t \left[f_t \cdot Q_t \cdot \sum_{\text{d}} \left(f_{d,t} \cdot K_{dt} \right) \right] \tag{3}$$

where, $Q_{running}$ is emission factor in running, g/km; $\bar{U}_{FTP}$ is the average velocity of vehicles under LA4 standard working condition, km/h; *D* is the mileage, km; $\bar{U}_C$ is the average velocity of vehicles under specific operating conditions, km/h; f_t is the proportion of the number of vehicles; Q_t is the average emission factor, km/h; f_{dt} is the proportion of the running state or hot soak time; K_{dt} is correction factor; Q_{start} is emission factor in start-up, g;

Vehicle specific power (VSP) and engine stress (ES) are introduced into the IVE model for a more accurate estimation of emission factors (Liu et al., 2012). VSP is the instantaneous operating state of vehicles, expressed by the ratio of vehicle transient output power to vehicle mass and calculated as follows:

$$VSP = v(1.1a + 9.81\, atan\, sin\theta + 0.132) + 0.000302v^3 \tag{4}$$

where, a is the transient acceleration, m/s^2; θ is the road slope; v is velocity, m/s.

ES is the impact of the motor vehicle's historical operating performance on the present, which involves instantaneous velocity and the VSP of 20 seconds before the start-up. It is derived from the following equation.

$$ES = 0.08 \ \ P_{ave} + RPMindex \tag{5}$$

where, P_{ave} is the average VSP in the first 5s to the first 25s before start-up, kW/t; 0.08 is the empirical coefficient, t/kW; $RPMindex$ is the engine velocity index, which is the ratio of the transient velocity to the velocity splitting constant.

2.2 Guideline method

In this session, we refer to *the Technical Guidebook for On-Road Vehicle Air Pollutant Emissions* (the Guidebook) from the Ministry of Environmental Protection of China to quantify on-road vehicle emissions in Northeast China in 2014 (MEP, 2014). Based on the comprehensive benchmark emission coefficient (*BEF)* proposed from the Guidebook, we calibrated the emission coefficient with various inputs such as local information, mileages, vehicle type, fuel quality, as follows:

$$EF_{i,j} = BEF_i \times \varphi_j \times \gamma_j \times \theta_i \tag{7}$$

where, $EF_{i,j}$ is the emission factor of vehicle *i* in region *j*; BEF_i is the comprehensive benchmark emission factor of vehicle *i*; φ_j is the environmental correction factor of region *j*, γ_j is the average velocity correction factor of region *j*, θ_i is the other correction factor of vehicle *i* .

3. Data acquisition

3.1 Route for vehicle testing

This paper takes Changchun City in Northeast China as an example to explore the vehicle emission factors calculated by different methods. We sampled from Chaoyang and Erdao Districts on weekdays and weekends, including peak hours and off-peak hours. Chaoyang and Erdao Districts are selected as representatives of urban commercial and residential districts, respectively (Fig. 1). This paper further analyzed vehicle emissions from different types of roads, including expressway, main roads, secondary roads and residential roads (Ericsson, 2000; Brundell-Freij et al., 2005).

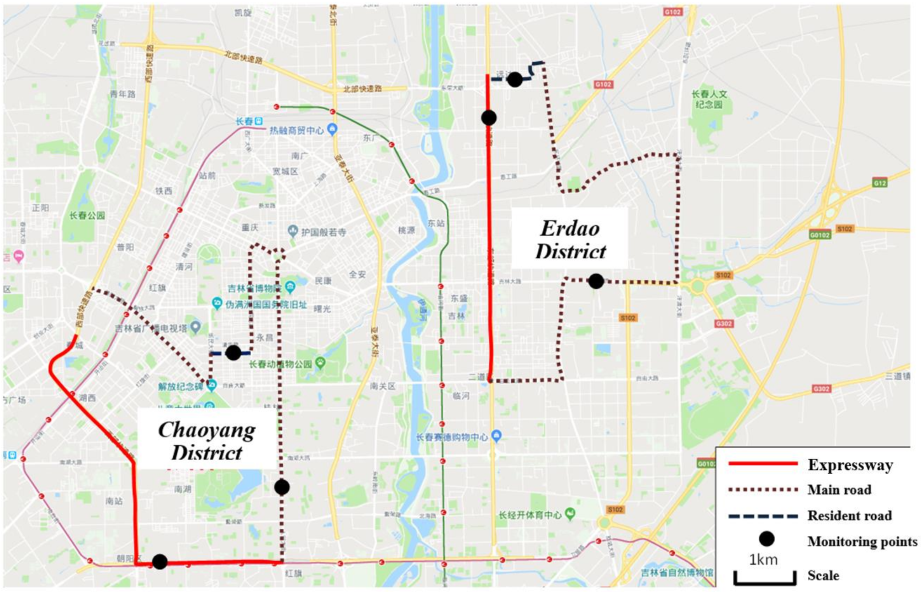


Fig. 1 Test route

3.2 Test methods

The portable vehicle positioner was used in the tests of light gasoline vehicles (Toyota pra), light CNG vehicle (Volkswagen Jetta) and buses on different roads. Repeated testing was conducted to improve accuracy. Monitoring points were set on different types of roads, including the expressway, main roads, secondary roads and residential roads, respectively. The HT3000-E mobile high-definition capture instrument was used to obtain the vehicle components of different periods on typical roads. Information of vehicles (including vehicle age, pollutant control technology, mileage, fuel type, hot soak time, etc) was obtained through questionnaires. In addition, local information and oil quality were derived from monitoring or investigation.

4. Results and discussion

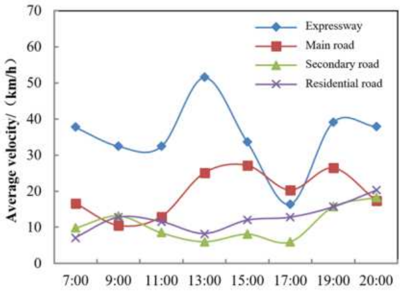
4.1 Operating condition analysis

4.1.1 Light gasoline vehicle

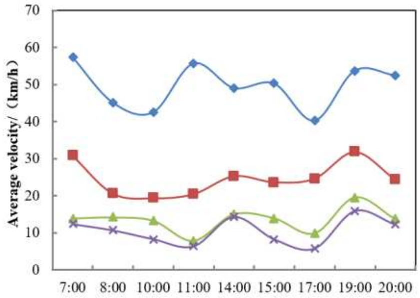
(1) Velocity distribution

The hourly average velocities of light gasoline vehicles in different functional areas and road types of Changchun City are shown in Fig. 2. The average velocity on expressway in weekdays is the highest in the business district, which is 41.69 km/h, followed by main roads (19.57 km/h), secondary roads (10.65 km/h) and residential roads (12.53 km/h). The velocities on expressway and main roads show typical bimodal distribution over time.

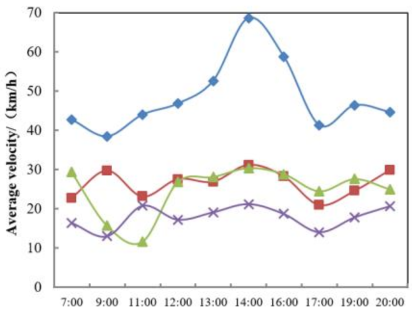
For the working days in residential areas, the maximum velocities occurred on expressway (48.5 km/h), main road (26.5 km/h), secondary road (24.8 km/h) and residential road (17.9 km/h) are 16.3%, 35.5%, 132.9% and 43.1% higher than the same type of road in commercial areas, respectively. This means that the traffic condition of residential area is better than that of commercial area.



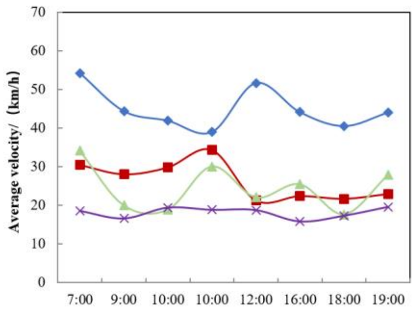
(a) Business district in weekdays



(b) Business district in weekends



(c) Residential district in weekdays

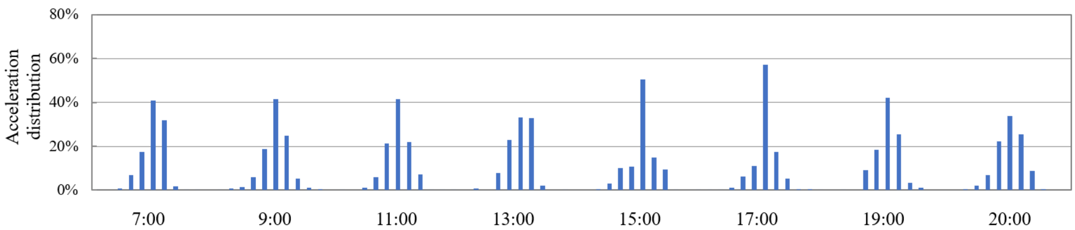


(d) Residential district in weekends

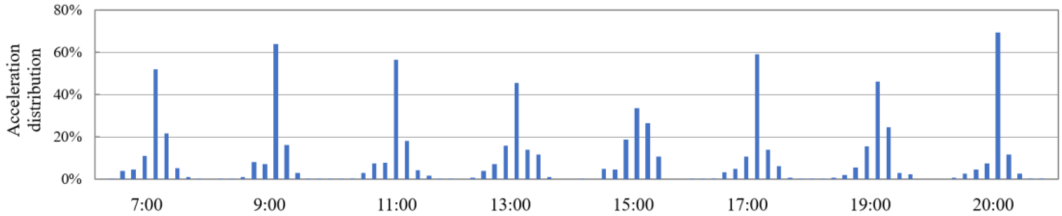
Fig. 2 Averaged velocity distribution in typical road

(2) Acceleration distribution

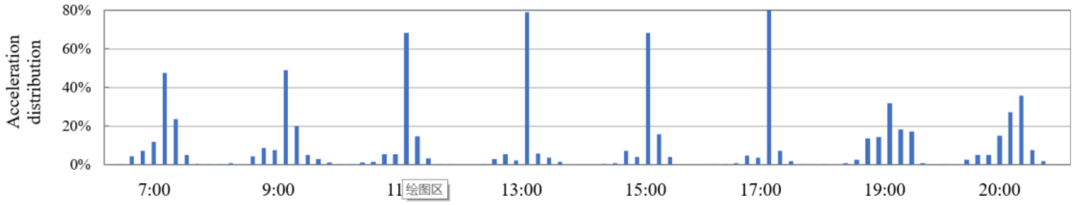
The acceleration distribution of motor vehicle during running stage is shown in Fig. 3. From left to right, the driving states are fast deceleration (a<-1.5), high deceleration (-1.5 ≤a<-1.0), medium deceleration (-1.0≤a<-0.6 and -0.6≤a-0.3), slow deceleration (-0.3≤a<-0.1), uniform velocity (-0.1≤a<0.1), slow acceleration (0.1<a≤0.3), medium acceleration (0.3<a≤0.6 and 0.6<a≤1.0), high acceleration (1.0<a≤1.5) and fast acceleration (a>1.5), respectively.



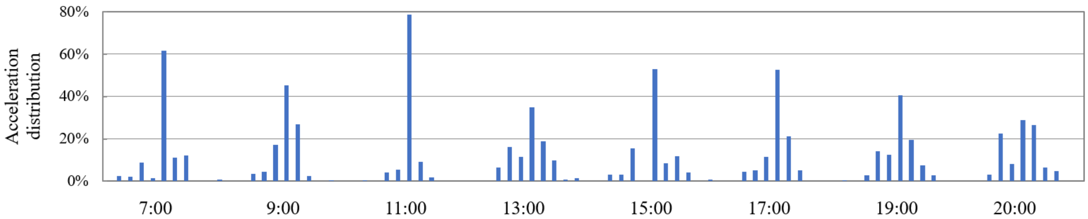
(a) Expressway



(b) Main road



(c) Secondary road



(d) Residential road

Fig. 3 Acceleration distribution of typical roads over time

From the perspective of space, the acceleration distribution on different roads is obviously different. For example, the temporal distribution of uniform velocity on the secondary roads is the largest (57%), followed by main roads (54%), residential roads (49%) and expressway (43%). The acceleration distribution is also different in different periods. During the rush hour, most of the vehicles drive at a constant velocity or slow acceleration and deceleration.

4.1.2 Light CNG vehicle and bus

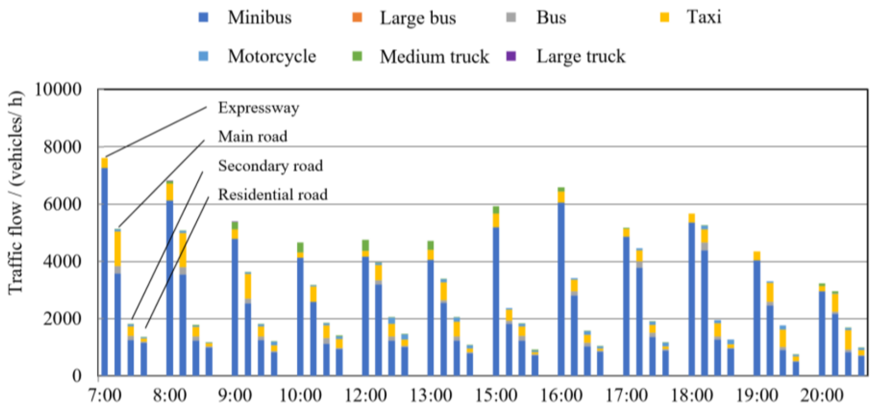
For light CNG vehicle, the vehicle's average velocity shows a wavy distribution over time, among which the average velocity in uniform velocity driving is the largest (44.66 km/h), followed by deceleration driving (36.09 km/h), and acceleration driving (29.38 km/h), respectively. The velocity maxima mainly occur at 11:00, 21:00, 5:00 and 8:00.

The operating conditions of buses are related to road types and urban functions. In other words, rural operating conditions are better than operating conditions. However, there is no distribution in medium and high load areas, indicating that the operating conditions of buses are generally poor. The velocity of buses fluctuates greatly, with frequent acceleration and deceleration.

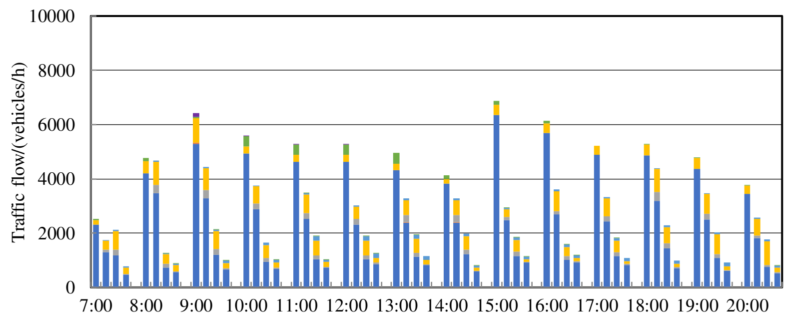
4.2 Fleet composition and technical distribution

4.2.1 Fleet composition

Fig. 4 shows the hourly traffic flow and fleet composition on typical roads.



(a) Working days



(b) Rest days

Fig. 4 Traffic flow and fleet composition on typical roads

The traffic flow in Changchun City is wavy over time. The peak value of hourly traffic flow on weekdays is around 7:00 and 18:00, which is consistent with the peak time of commuting. The expressway has the largest traffic volume (5,405 vehicles/h), followed by main roads (3,843 vehicles/h), secondary roads (1,834 vehicles/h) and residential roads (1,153 vehicles/h). The road traffic on weekends is less than weekdays. The average traffic flow of the expressway, main roads, secondary roads and residential roads is 5,073, 3,422, 1,875 and 1,004 vehicles/h, respectively. Their peak value appears around 9:00, 15:00 and 18:00.

For the distribution of vehicle type, small passenger cars accounted for the largest proportion (70%), followed by taxis (15%) and buses (4%). The proportion of small passenger cars in expressway is as high as 90.3%, and the proportion of buses and motorcycles is almost zero. The proportions of small passenger cars on main roads and secondary roads are lower than that on expressway, which are 76% and 61%, respectively. In addition, the proportion of motorcycles on residential road and secondary road is significantly higher than the other two types of roads.

4.2.2 Distribution of motor vehicle technology

(1) Light gasoline vehicle and light CNG vehicle

Light gasoline vehicles are mainly medium-sized vehicles (78%), followed by light vehicles (21%), heavy vehicles (1%). These vehicles are mainly National IV and V, of which the proportion of National IV and V is as high as 88%, and the proportion of national III models is only 12%. The proportion of accumulated mileage less than 79×10^3 km is the largest (84.4%), and that greater than 161×10^3 km is the smallest, only 4.2%. The average daily starts of light gasoline vehicles is about 3.4, among which the daily starts of railway station is the most, about 4.8.

Control standards of exhaust emission of vehicles are mainly National IV and V, both of which are 50%. The registration time of these vehicles is mostly after 2011. The annual mileage is about 95×10^3 km ~ 120×10^3 km. The flameout time of light CNG vehicles is mainly 15-30 min (57%), followed by 0-15 min (14%), 30 min-1 h (14%) and 12 h-18 h (14%).

The average age of light CNG vehicle is about 4.1 years. 78% of vehicles are under 5 years old. The accumulated mileage of light gasoline vehicles is mostly within 100×10^3 km, and it gradually increases with the increase of service life.

(2) Buses

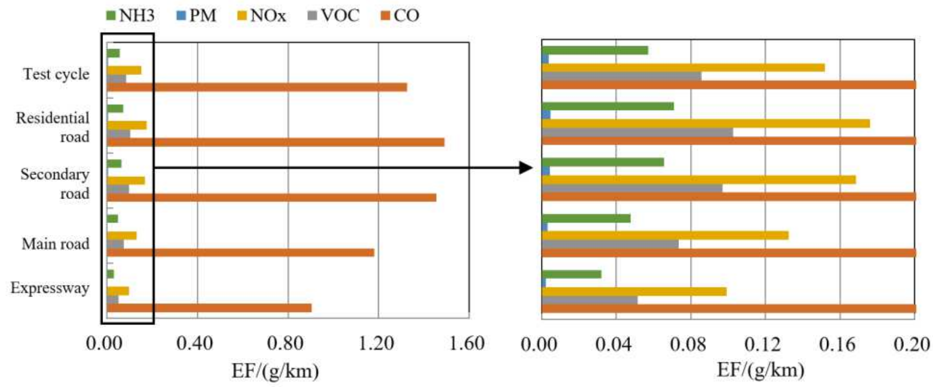
The fuel of Changchun City's buses is mainly clean energy (CNG, LNG), accounting for about 80%. New energy vehicles (includes steam hybrid vehicles, plug-in hybrid vehicles and pure electric vehicles) only account for about 3%. Traditional gasoline buses account for about 17%. Medium-sized buses account for the largest proportion (58%), followed by heavy-duty buses (38%) and light buses (4%). The daily average mileage of buses is more than 200 km, and the cumulative average mileage is above 200×10^3 km. For the emission control standard, the national IV vehicles have the largest proportion, accounting for 48%, followed by the national V (31%) and III (21%) vehicles.

4.3 Emission factors and influencing factors based on the IVE model

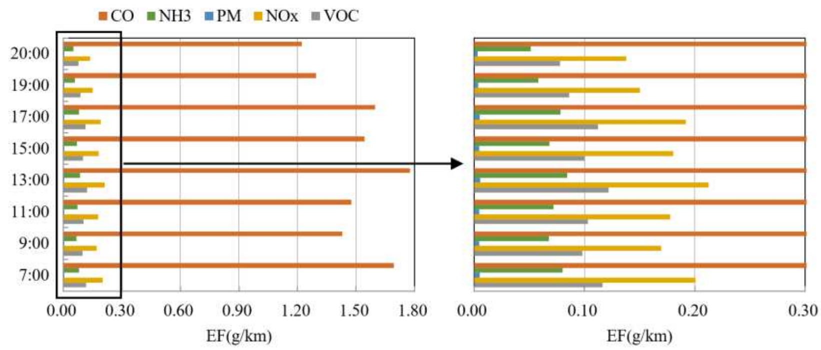
4.3.1 Light gasoline vehicle

(1) Emission factor

Fig. 5 shows the emission factors of light gasoline vehicles on different roads and in different periods.



(a) Emission factors of light gasoline vehicles on different roads



(b) Emission factors of light gasoline vehicles in different periods.

Fig. 5 Emission factors of light gasoline vehicles on different roads and in different periods

The emission factor of vehicle emissions on residential roads is significantly higher than that of other roads. The emission factors show a certain regularity over time, which is related to the operating conditions of vehicles. For example, the traffic conditions in the morning (7:00) and evening peak periods (17:00) are poor, and its emission factors are relatively large, while the flat valley period is relatively small.

(2) Velocity effect

Fig. 6 shows emission factors of pollutant NH_3 at different velocities.

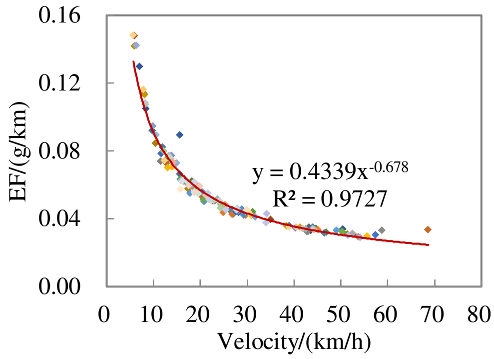
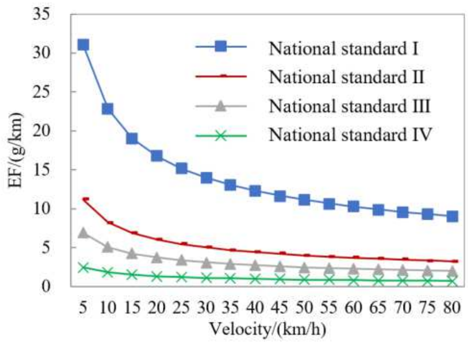


Fig. 6 Emission factors of pollutant NH_3 at different velocities

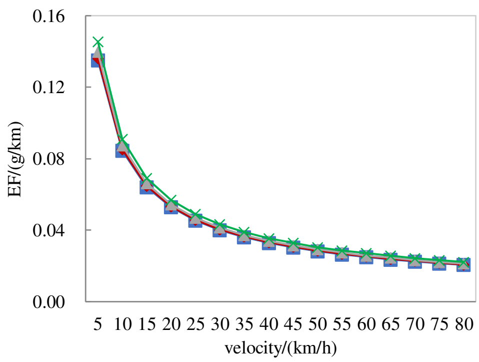
The emission factors of CO, NOx, VOC, PM and NH_3 decrease with the increase of velocity. The changes in emission factors of these five pollutants are similar, which is that the decreasing trend gradually slows down. Besides, it is found that there is a good mathematical relationship between the pollutant emission factors and velocity by function fitting. Most of the characterization parameters R^2 are above 0.9.

(3) Emission standard effect

Fig. 7 shows emission factors of different pollutants with different emission standards.



(a) CO



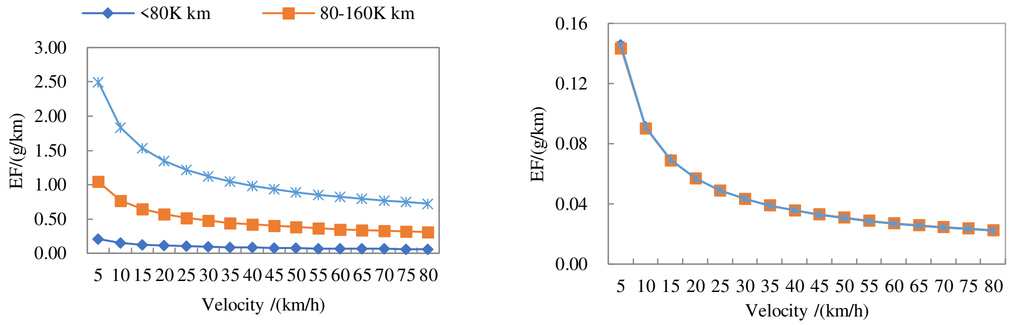
(b) NH_3

Fig. 7 Emission factors of different pollutants with different emission standards.

Except for NH_3, with the improvement of control standards, the overall pollutant emission factors show a downward trend. Among them, the emission factors of CO, VOC and NOx are significantly reduced. Taking CO as an example, the emission factors in National standards II, III and IV are 64%, 78% and 92% lower than those in national standards I, respectively. In other words, the potential for vehicle emission reduction is getting smaller and smaller with the improvement of emission standards.

(4) Accumulated mileage effect

Taking the light gasoline vehicle with National standard IV as an example, the impact of accumulated mileage on emission factors is shown in Fig. 8.



(a) CO (b) NH_3

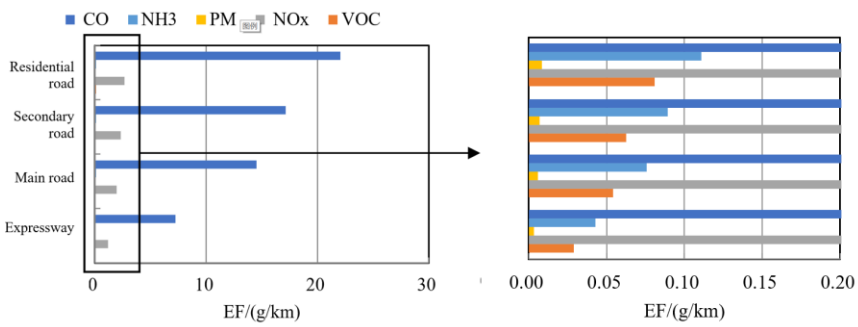
Fig. 8 Effect of accumulated mileage on emission factors

Except for NH_3, the emission factors of other pollutants increase with the increase of accumulated mileage, that is, the deterioration coefficient of vehicles increases gradually. Taking CO as an example, the degradation rate of emission factors in 80×10^3 km and 160×10^3 km is 0.048g/km and 0.081g/km, respectively, which indicates that the degradation rate of vehicles increases gradually with the increase of driving mileage.

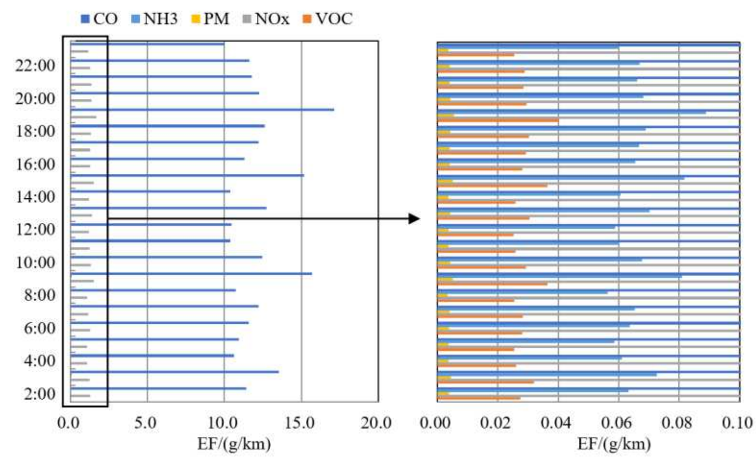
4.3.2 Light CNG car

(1) Emission factor

Fig. 9 shows the emission factors of light CNG vehicles on different roads and in different periods. In general, the highest emission factors occur in residential roads, followed by secondary roads, main roads and expressway. Taking CO as an example, the emission factor on the expressway is 7.243g/km, which is 2.0, 2.4 and 3.0 times of main road, secondary road and residential road, indicating that the road type is an important factor affecting emission factors of light CNG vehicles.



(a) Emission factors of light CNG car on different roads



(b) Emission factors of light CNG car in different periods

Fig. 9 Emission factors of light CNG car on different roads and in different periods

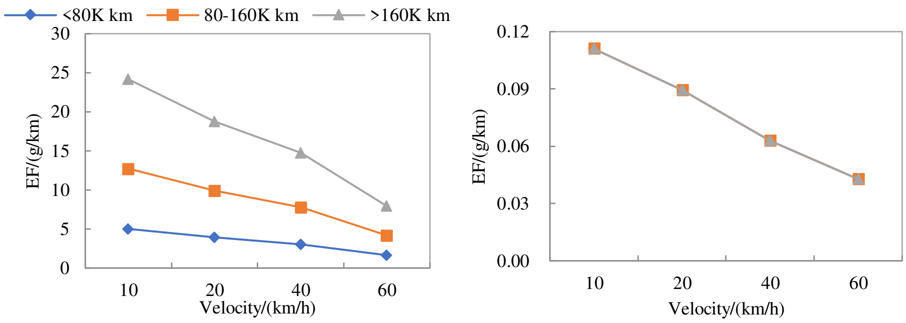
The five emission factors have similar trends in time distribution. The peak value mainly occurs at 9:00, 15:00 and 19:00, which is related to the high traffic density, low velocity and aggressive driving. The average emission factors of CO, VOC, NOx, PM and NH_3 are 12.152 g/km, 0.029 g/km, 1.297 g/km, 0.004 g/km and 0.067 g/km, respectively. By comparing the emission factors between daytime (9:00-19:00) and nighttime (20:00-8:00), it is found that emission factors of CO, VOC, NOx, PM and NH_3 at daytime are 12.776, 0.031, 1.373, 0.004 and 0.070g/km, respectively, which are 10.8%, 10.6%, 12.6%, 9.8% and 9.8% higher than that of nighttime. The traffic flow at nighttime is small and the velocity is large, which is opposite to the traffic condition at daytime. The latter results in incomplete combustion of the engine and a large number of pollutants are emitted.

(2) Velocity and emission standard effect

The emission factors of light CNG vehicles decrease with the increase of velocity, which is similar to the emission rules of light gasoline vehicles, so it will not be discussed here. Besides, since the light CNG vehicles in Changchun are mostly oil to gas vehicles, the tail gas treatment technology of gasoline vehicles is not suitable for CNG fuel vehicles. Therefore, this paper does not discuss the effect of emission standards.

(3) Accumulated mileage effect

Fig. 10 shows emission factors of different pollutants with different accumulated mileages. Except NH_3, the emission factors of other pollutants gradually increase with the increase in accumulated mileage. Like light gasoline vehicles, the deterioration rate of light CNG vehicles increases with the increase of accumulated mileage. Taking CO and NOx as examples, the degradation rate of 80×10^3 km and 160×10^3 km is 0.655, 0.970, 0.023 and 0.035g/km, respectively. It shows that the degradation rate of light CNG vehicle increases with the increase in mileage.



(a) CO (b) NH_3

Fig. 10 Emission factors of different pollutants with different accumulated mileages

4.3.3 Bus

(1) Emission factor

The pollutant emission factors of buses at different velocities are shown in Fig. 11. The emission factors are generally decreasing with the increase of velocity. The average emission factors of CO, NOx, VOC, PM and NH_3 are 4.835, 0.200, 0.032, 0.005 and 0.036g/km, respectively.

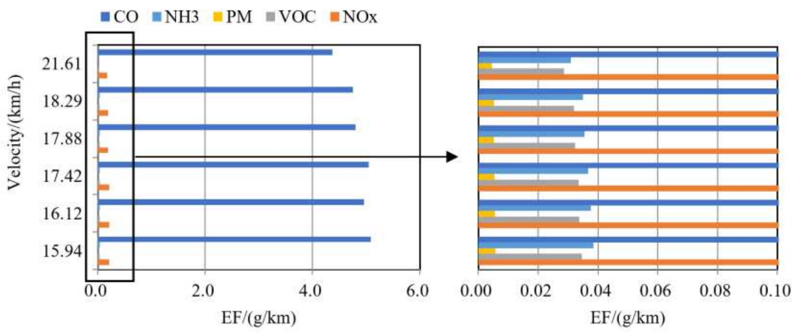


Fig. 11 Emission factors for pollutants of bus

(2) Fuel type

About 80% of buses in Changchun use clean energy. But about 20% of the buses are gasoline vehicles, which results in a large contribution rate of pollutant emission in public transportation. The emission factors of CO, NOx, VOC, PM and NH_3 of gasoline buses are 31.002, 1.557, 2.461, 0.023 and 0.029 g/km, respectively, which are 6.4, 7.8, 75.9, 4.3 and 0.8 times of those of CNG fuel vehicles. It can be seen that CNG fuel can significantly reduce pollutant emissions, especially VOC emissions.

(3) Emission standard effect

Fig. 12 shows emission factors with different emission standards. With the improvement of emission standards, the emission factors of pollutants gradually decrease. When the emission standard is raised from national II to V, the emission factors of CO, VOC, NOx and PM are reduced by 69%, 68%, 66% and 66%, respectively. It can be seen that with the improvement of emission standards, the effect of pollutant emission reduction is more obvious.

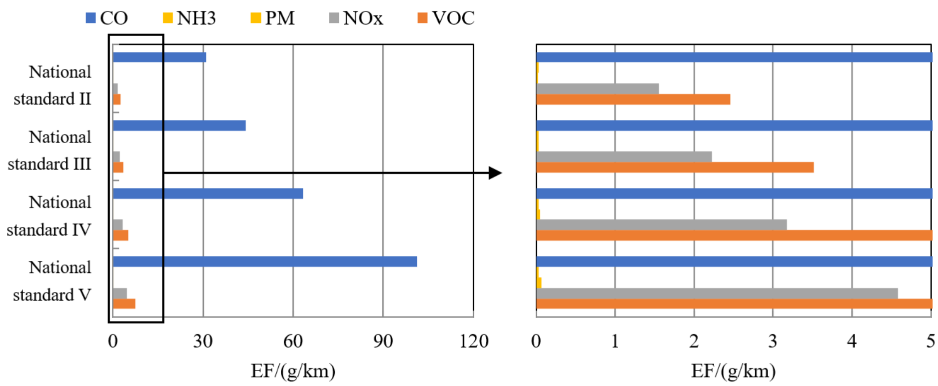


Fig. 12 Emission factors with emission standards

(4) Accumulated mileage effect

Emission factors of buses under different accumulated driving mileage are shown in Table 1. Except for NH_3, the emission factors of other four pollutants increased with the increase in accumulated mileage, that is, the deterioration coefficient of vehicles increased gradually. Taking gasoline bus with the national standard V as an example, the degradation rate of CO with 80×10^3 km and 160×10^3 km is 0.483 and 0.746g/km, respectively, and the latter is 1.54 times of the former.

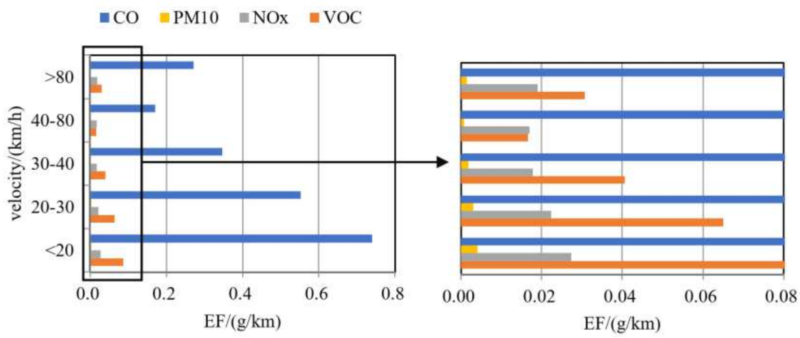
Table 1 Emission factors of buses under different accumulated mileage

Accumulated mileage/	CNG/(g/km)					gasoline /(g/km)				
$\times10^3$ km	CO	NO_x	VOC	PM	NH_3	CO	NO_x	VOC	PM	NH_3
<80	4.470	0.170	0.025	0.002	0.035	21.175	1.226	1.829	0.009	0.029
80～160	4.502	0.181	0.028	0.002	0.035	25.037	1.371	2.104	0.008	0.029
>160	4.799	0.198	0.032	0.005	0.035	31.002	1.557	2.461	0.023	0.029

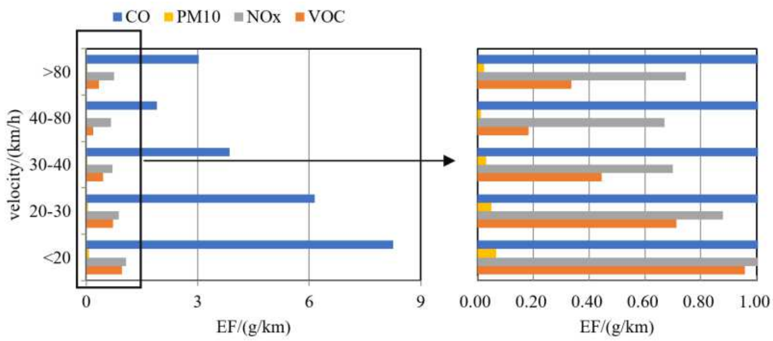
4.4 Emission factors based on the guideline method

Fig. 13 shows the pollutant emission factors of light gasoline vehicles with national standard V, gasoline bus with national standard V and CNG-fueled passenger vehicle.

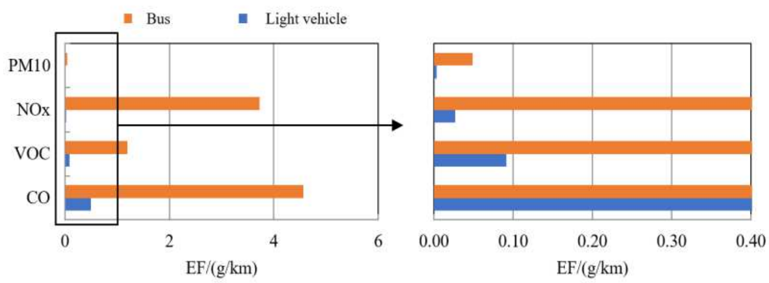
For light gasoline vehicles, the emission factors of different pollutants are similar to the change of velocity, as shown in Fig. 13(a). When the velocity is less than 80 km/h, the pollutant emission factor decreases with the increase in velocity. The emission factors of gasoline buses with national V standards are similar to those of light gasoline vehicles, as shown in Fig. 13(b). The average emission factors of CO, VOC, NOx and PM_{10} are 4.640, 0.527, 0.814 and 0.037g/km, respectively. The emission factor of buses is much higher than that of light vehicles, as shown in Fig. 13(c). The emission factors of CO, VOC, NOx and PM of CNG fuel buses are 4.570, 1.192, 3.728 and 0.049 g/km, which are 0.6, 1.2, 3.5 and 0.7 times of those of gasoline bus, respectively.



(a) light gasoline vehicles with national standard V



(b) gasoline bus with national standard V



(c) CNG-fueled passenger vehicle

Fig. 13 Emission factors of light gasoline vehicles with national standard V, gasoline bus with national standard V and CNG fuel passenger vehicle

4.5 Comparative analysis

4.5.1 Comparison of on-road measurement and guideline method

A comparison of emission factors between on-road measurement and guideline method is shown in Table 2. For the gasoline vehicle with national standard V, the measured results of CO and VOC emission factors are similar to the guidelines, with only 3% and 11% difference. However, NOx-measured are about three times those of the guideline method, indicating that the NOx emission factor of Changchun City for gasoline vehicles with national V standard based on the guideline is somewhat underestimated.

Table 2 Comparison of measurement and guideline method

Methods	Gasoline vehicles with national V standard / (g/km)			Gasoline vehicles with national VI standard / (g/km)			CNG vehicles with national VI standard / (g/km)		
	CO	VOC	NO_x	CO	VOC	NO_x	CO	VOC	NO_x
Guideline method	0.416	0.048	0.019	0.615	0.064	0.039	0.500	0.091	0.027
On-road test	0.334	0.036	0.060	2.600	0.060	0.465	1.007	0.461	0.937

For the gasoline vehicle with national standard VI, the actual emissions of CO and NOx are significantly higher than the guideline, which are about 4 and 12 times that of the guideline, respectively, while the VOCs are closer.

For the CNG vehicle with national standard VI, the measured emission factors of CO, VOC and NOx are about 2, 5 and 40 times that of the guideline, respectively. On the one hand, light CNG vehicles are mostly modified vehicles, resulting in insufficient combustion. On the other hand, long-term driving, high-load driving, irregular maintenance and insufficient combustion lead to the pollutant emission exceeding the standard.

4.5.2 Comparison of on-road measurement and IVE model

The comparitive results on emission factor between the on-road measurement and the IVE model are presented in Table 3. The emission factors of different emission standards and fuel types are different. Even at the same pollutant, the emission factor is different at different velocities. The simulation results of emission factors of light gasoline vehicles with National standard IV and V are close to the actual measured results, while the simulation results of emission factors of light CNG vehicles with national standard V are far from the actual measured results, which is related to the lag of technical parameters of vehicles in the IVE model.

Table 3 Comparison results between the on-road test and the IVE model

Velocity/	Correction factor of the IVE model

(km/h)	Light gasoline vehicles with National standard IV				Light gasoline vehicles with national standard V				Light CNG vehicles with national standard V			
	CO_2	CO	NO_x	VOC	CO_2	CO	NO_x	VOC	CO_2	CO	NO_x	VOC
10	1.33	2.18	4.02	1.71	1.27	0.51	0.42	4.49	0.56	0.02	0.34	11.93
20	1.27	2.33	3.54	1.67	1.19	0.52	0.76	3.82	0.60	0.02	0.42	13.58
30	1.08	3.51	2.89	1.76	1.20	0.30	0.60	4.21	-	-	-	-
40	1.21	3.33	2.65	1.85	1.20	0.85	0.78	3.84	0.68	0.07	0.56	9.63
50	1.18	2.84	3.01	1.63	1.17	0.72	0.81	3.45	-	-	-	-
60	1.21	3.14	2.42	1.36	1.16	0.61	0.68	3.61	0.69	0.18	0.45	10.69
70	1.14	3.09	2.70	1.81	1.18	1.30	0.86	4.05	-	-	-	-
80	1.15	3.04	2.14	2.16	-	-	-	-	-	-	-	-
Total	1.25	2.95	2.89	1.86	1.20	0.85	0.78	3.84	0.68	0.07	0.56	9.63

5. Conclusions

By analyzing the operating conditions, fleet composition and technology distribution of three typical vehicles, this study obtained the emission factors of typical motor vehicles based on IVE model and guideline method, and then analyzed their influencing factors. At last, comparative analysis between on-road measurement and guideline method and IVE model was conducted. The following conclusions were drawn.

(1) Regarding the operating conditions of motor vehicles, taking light gasoline vehicles as an example, its average velocity occurs on expressways at most (48.5 km/h). The proportion of motor vehicles with uniform vehicle on the secondary roads is the highest (57%). The highest traffic density occurs at 9:00 and 17:00 on weekdays.

(2) With the increase of velocity and emission standards, most emission factors of vehicles decrease. With the increase of accumulated mileage, most emission factors of vehicles increase.

(3) Compared with the actual emission factors, the emission factors of light gasoline vehicles with national V standard are overestimated, while those of other types of vehicles are underestimated. Compared with the actual emission factors, the emission factors of light duty gasoline vehicles obtained by IVE model are close to the actual ones, while the emission factors of light CNG vehicles with national standard V have great errors with the actual measurement.

Acknowledgements

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Figures

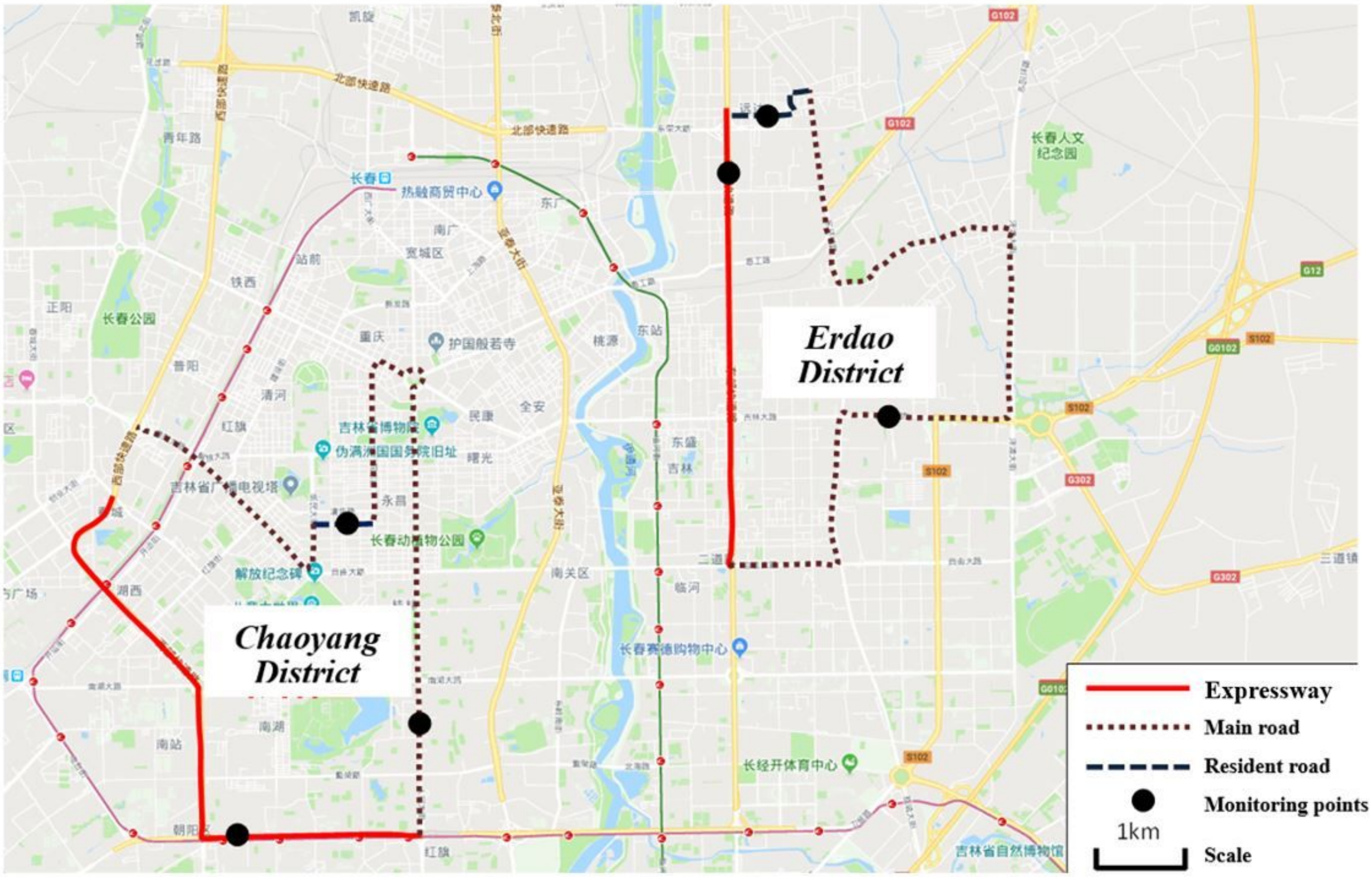
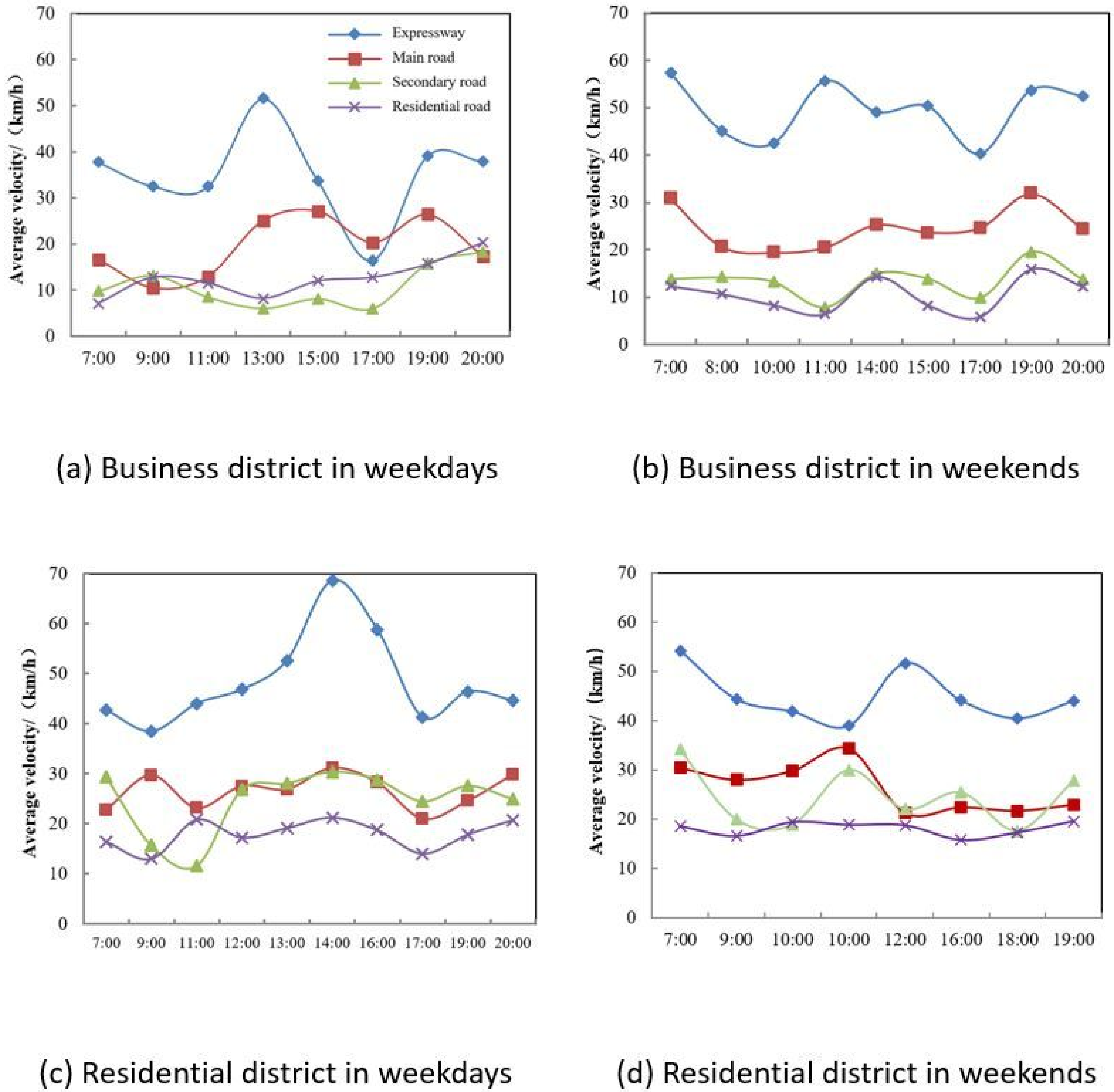


Figure 1

Test route Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.



(a) Business district in weekdays

(b) Business district in weekends

(c) Residential district in weekdays

(d) Residential district in weekends

Figure 2

Averaged velocity distribution in typical road

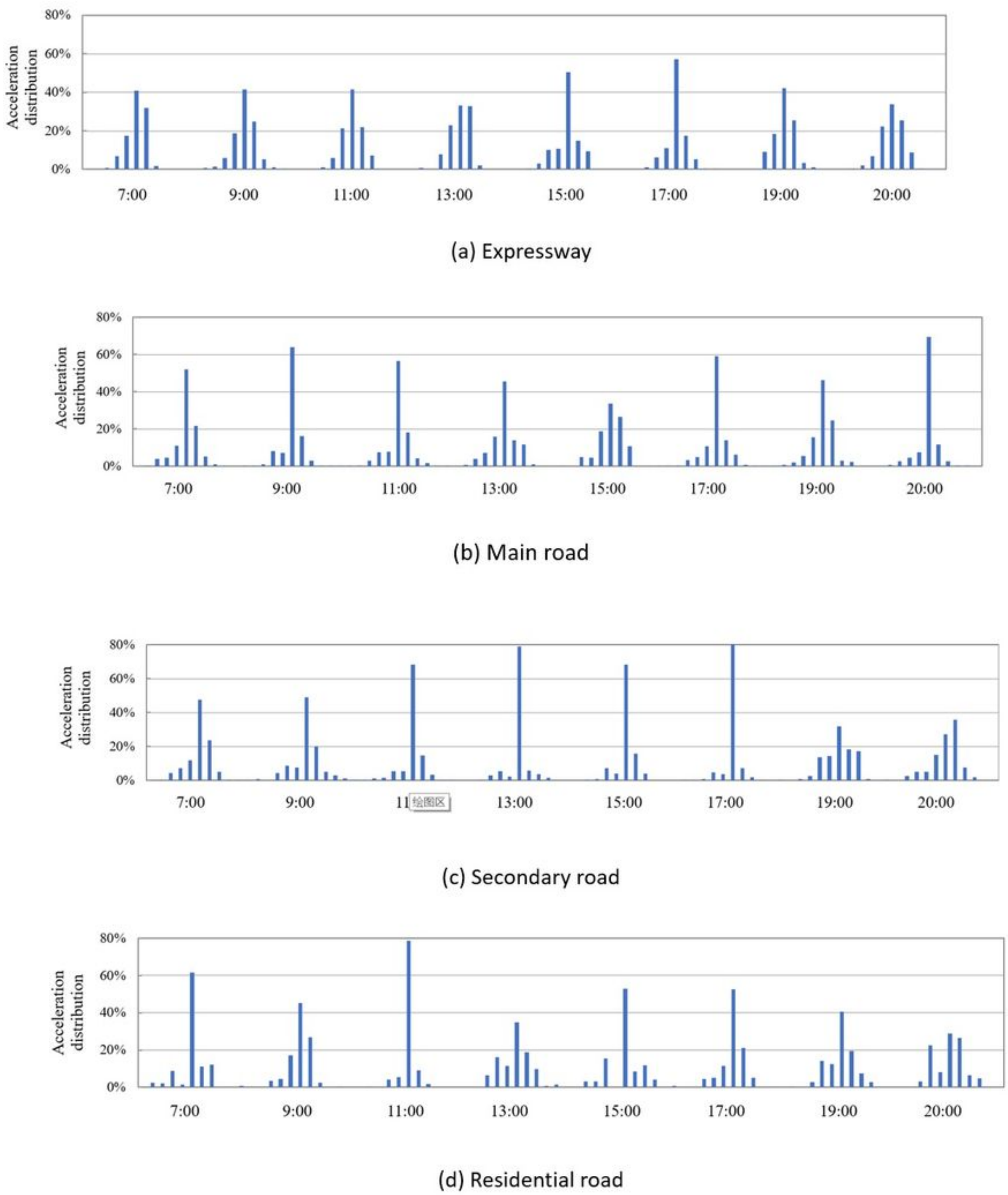
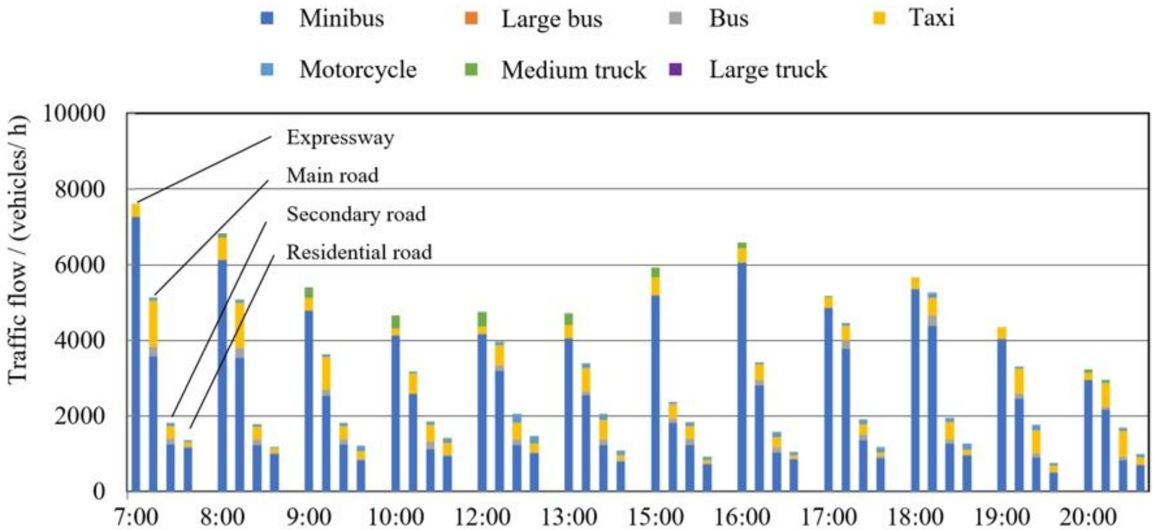
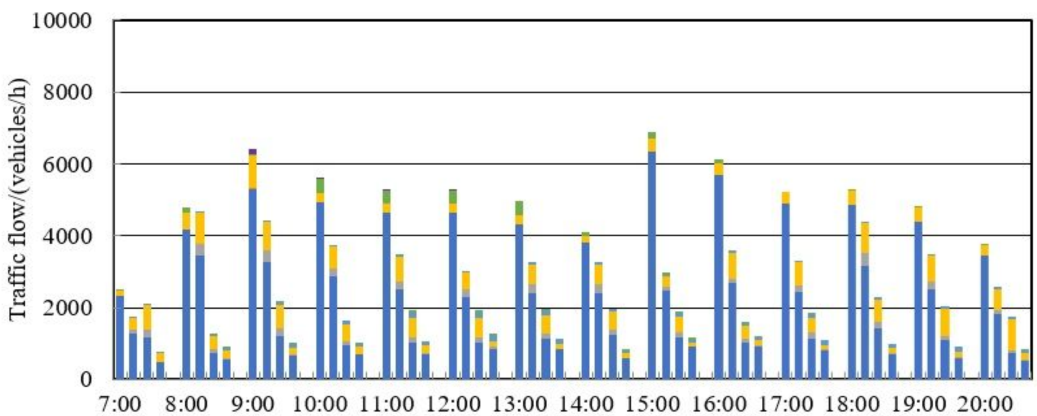


Figure 3

Acceleration distribution of typical roads over time



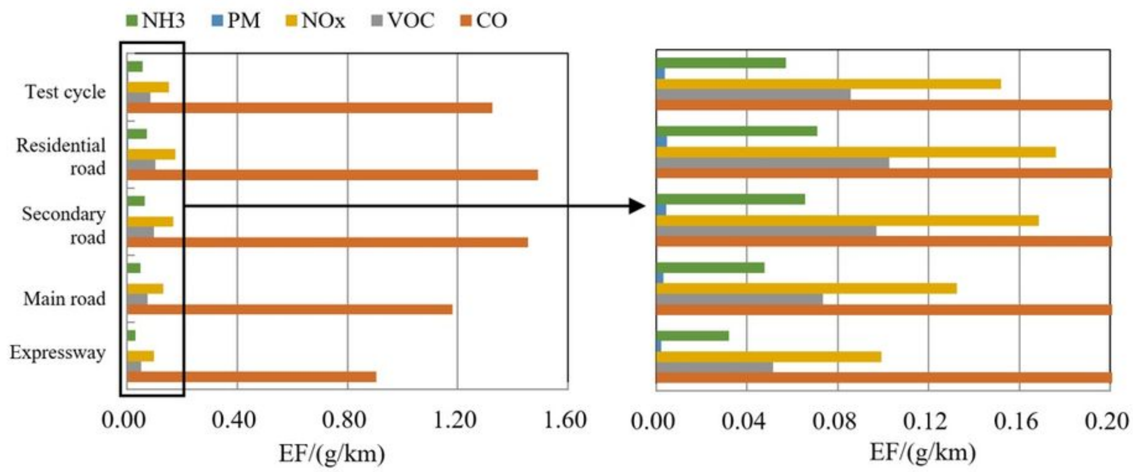
(a) Working days



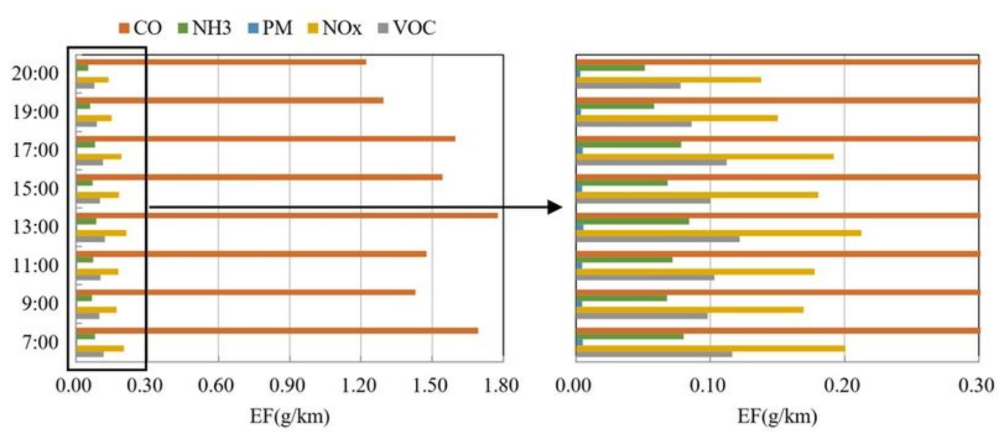
(b) Rest days

Figure 4

Traffic flow and fleet composition on typical roads



(a) Emission factors of light gasoline vehicles on different roads



(b) Emission factors of light gasoline vehicles in different periods.

Figure 5

Emission factors of light gasoline vehicles on different roads and in different periods

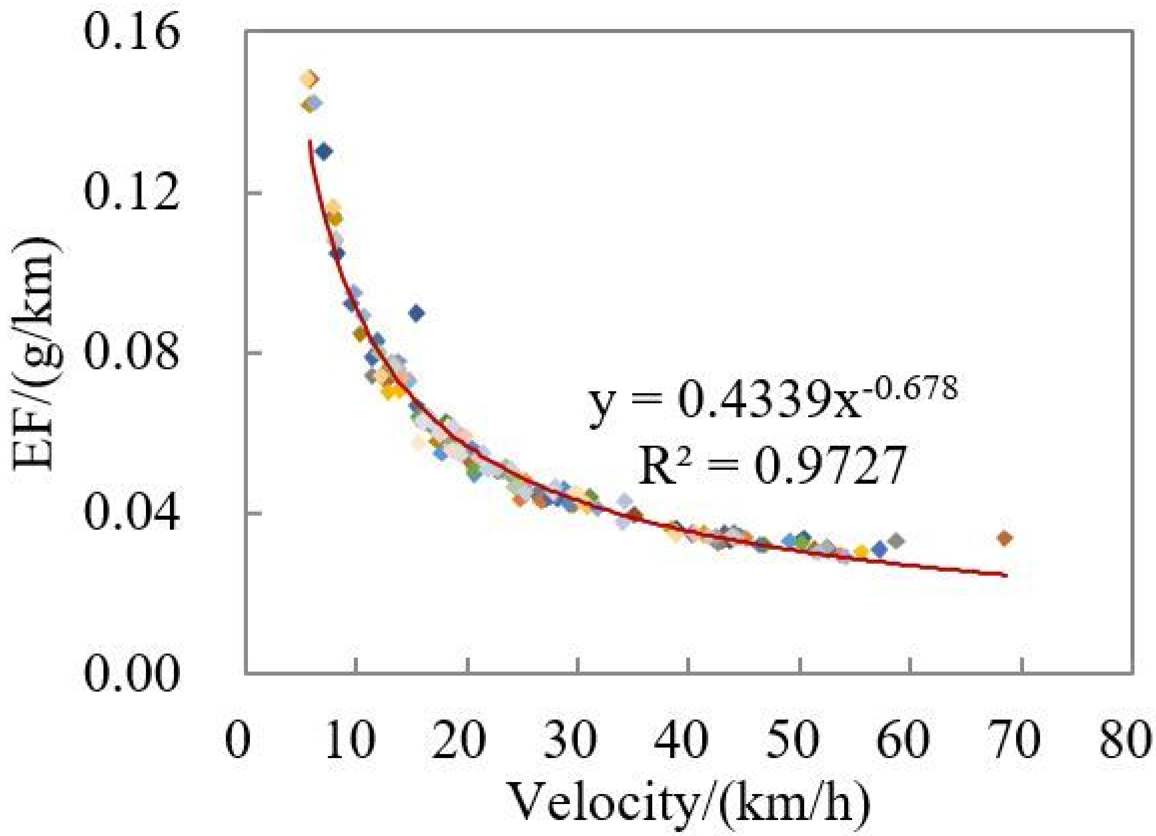


Figure 6

Emission factors of pollutant NH3 at different velocities

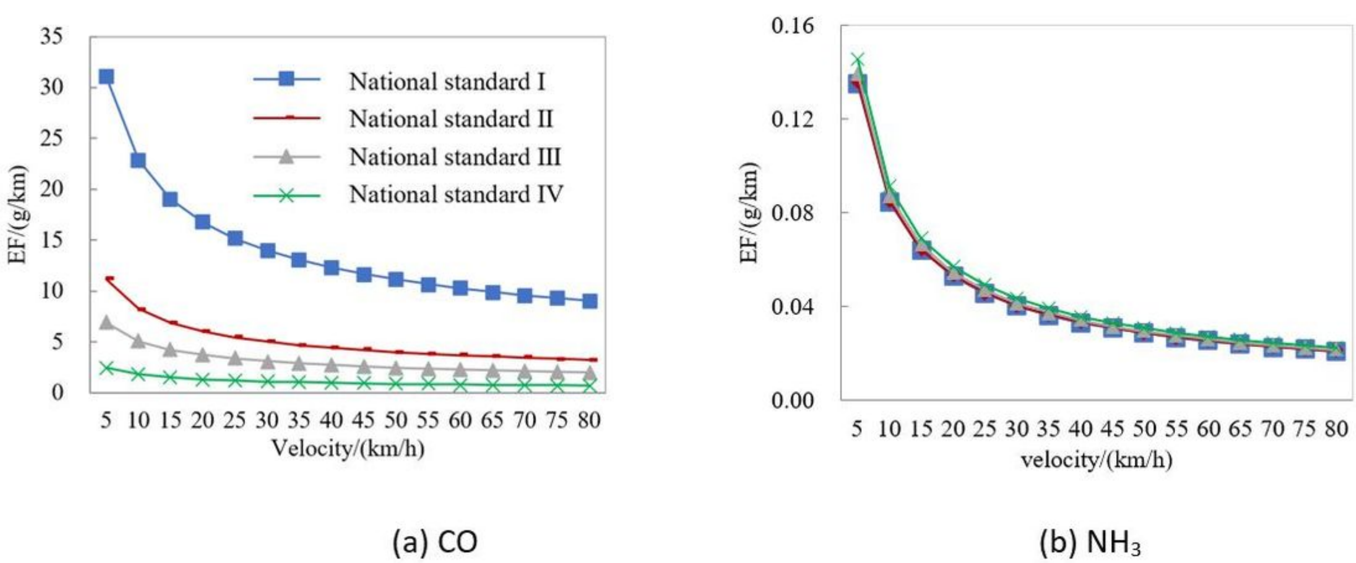


Figure 7

Emission factors of different pollutants with different emission standards.

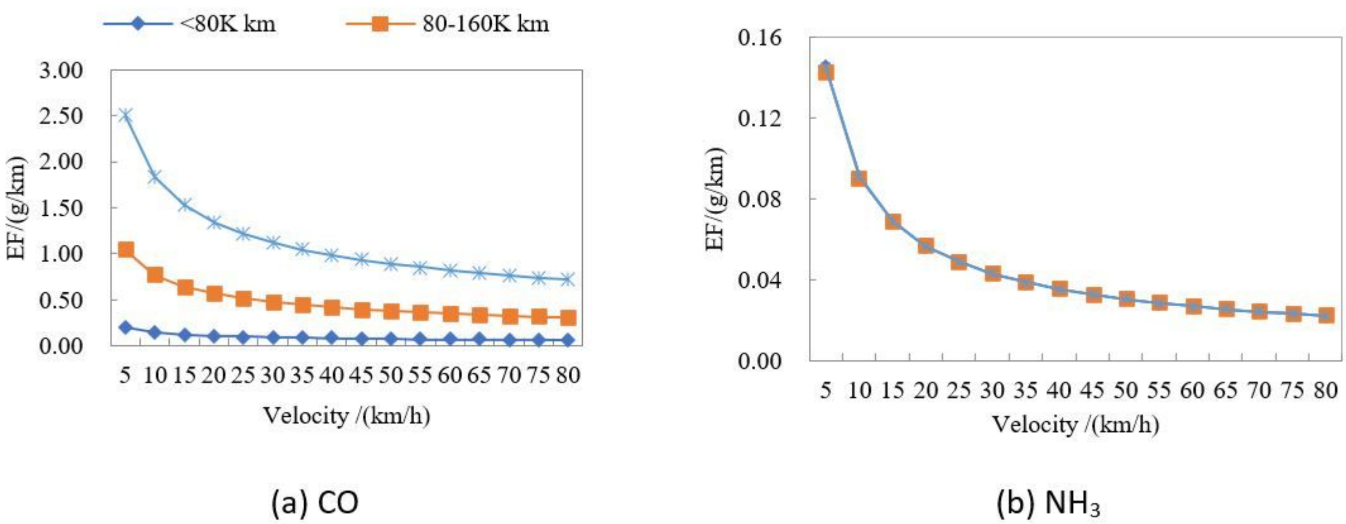
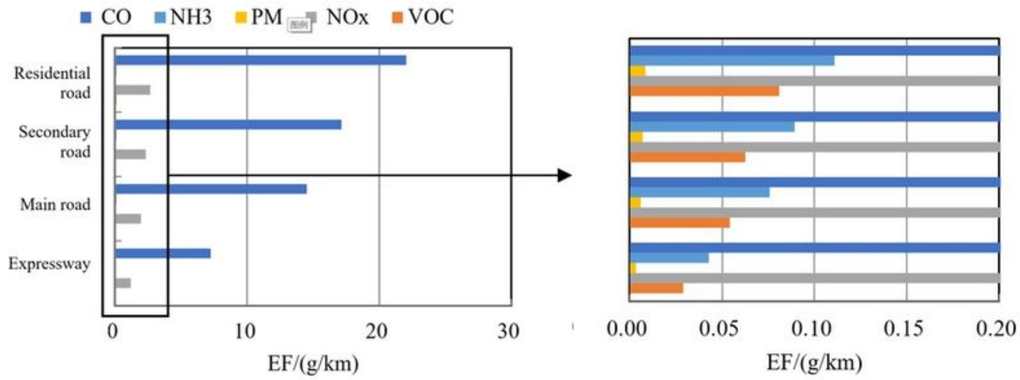
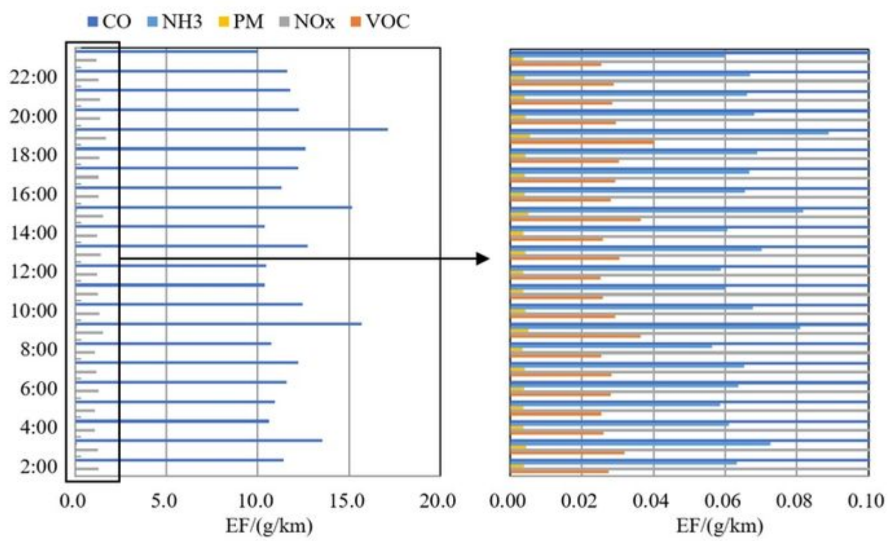


Figure 8

Effect of accumulated mileage on emission factors



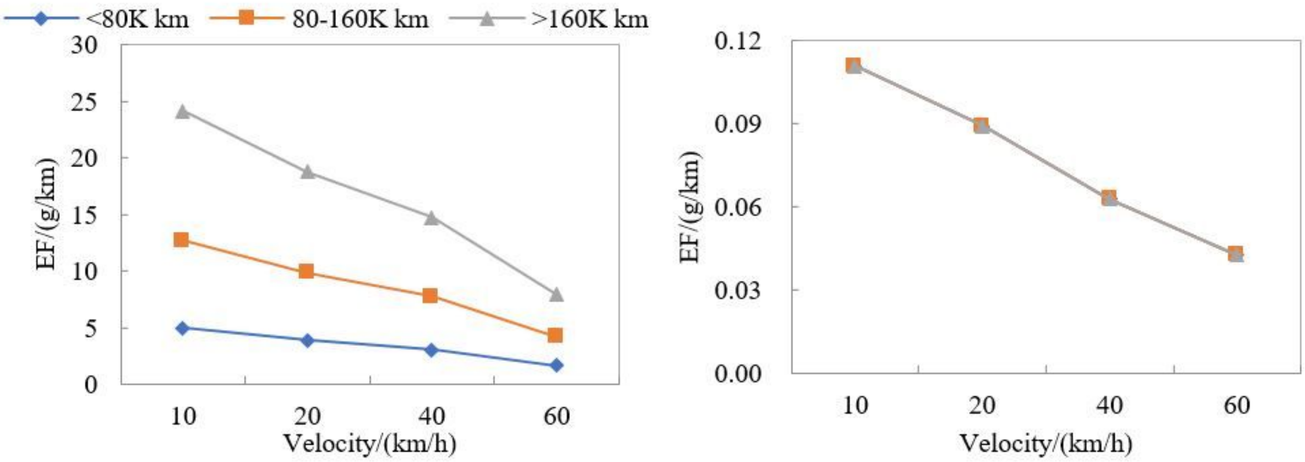
(a) Emission factors of light CNG car on different roads



(b) Emission factors of light CNG car in different periods

Figure 9

Emission factors of light CNG car on different roads and in different periods



(a) CO (b) NH_3

Figure 10

Emission factors of different pollutants with different accumulated mileages

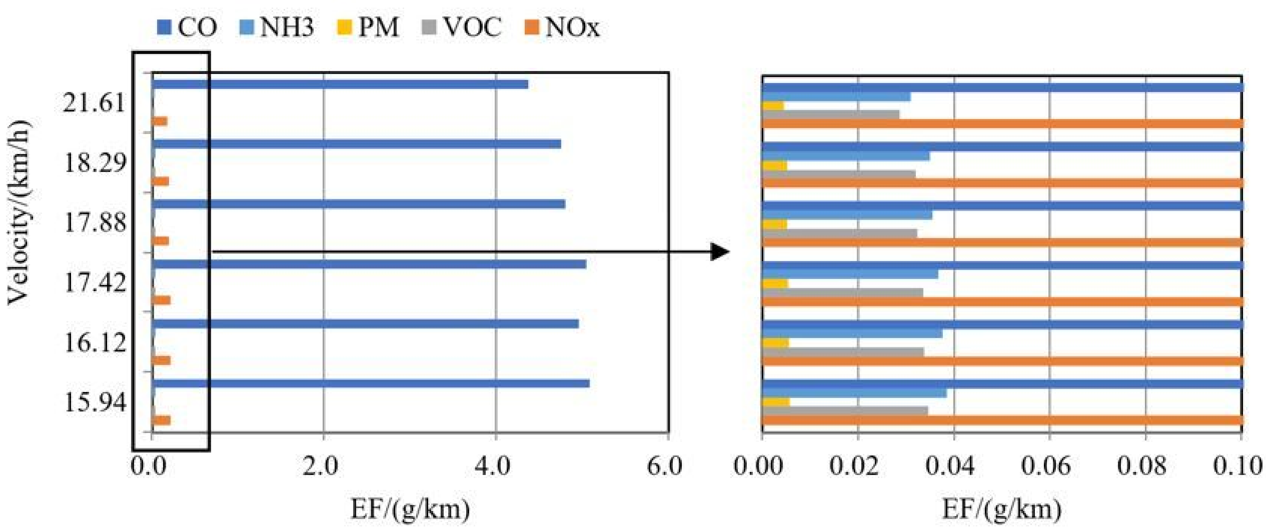


Figure 11

Emission factors for pollutants of bus

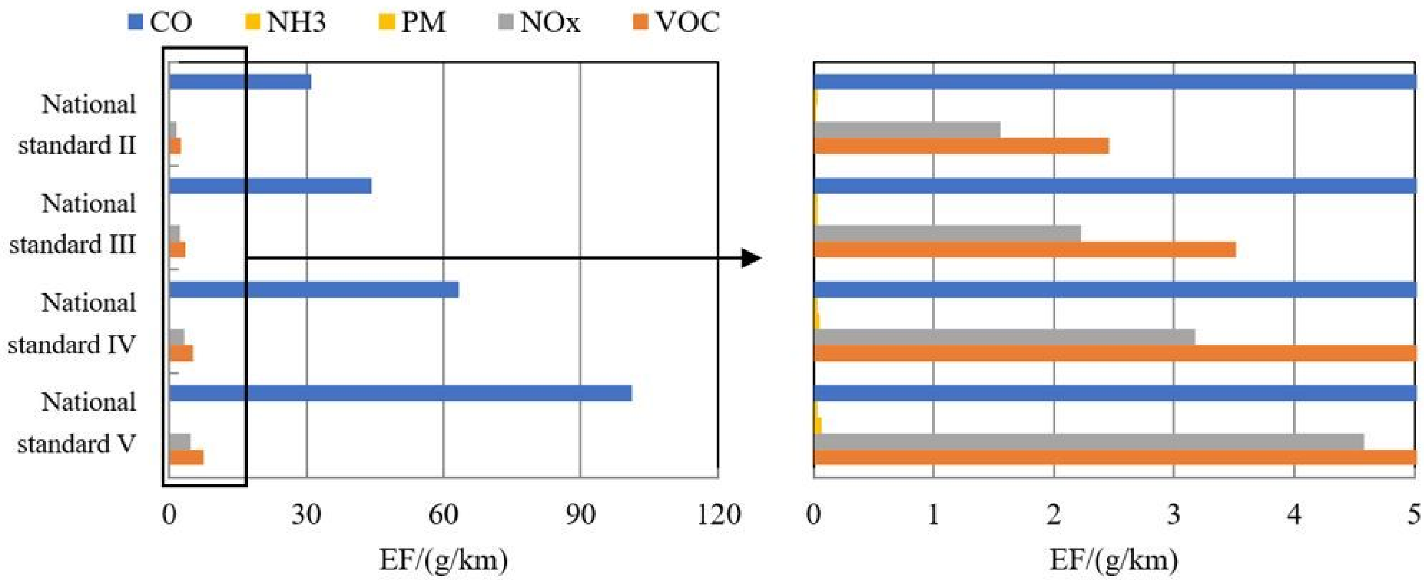
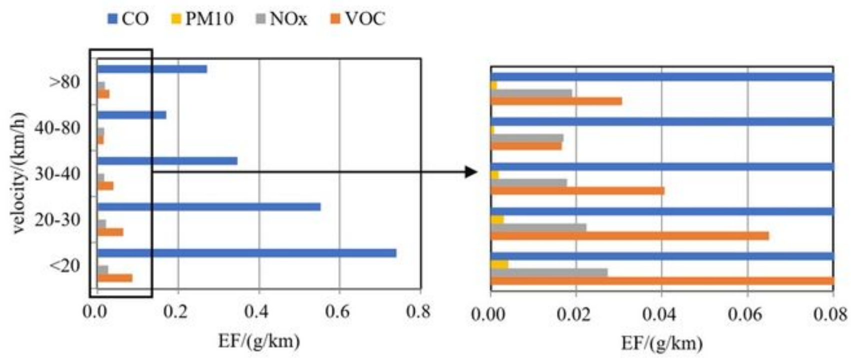
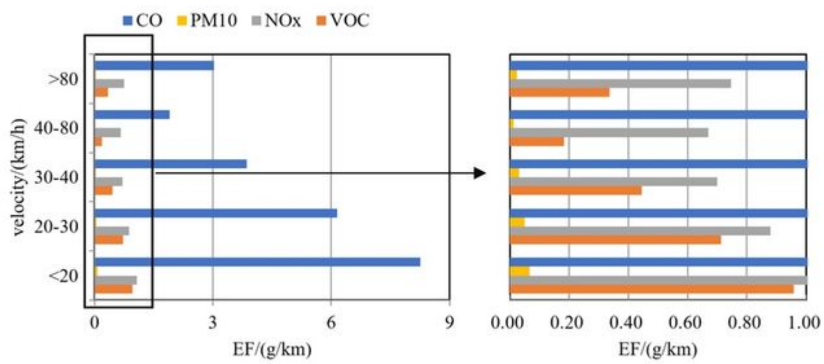


Figure 12

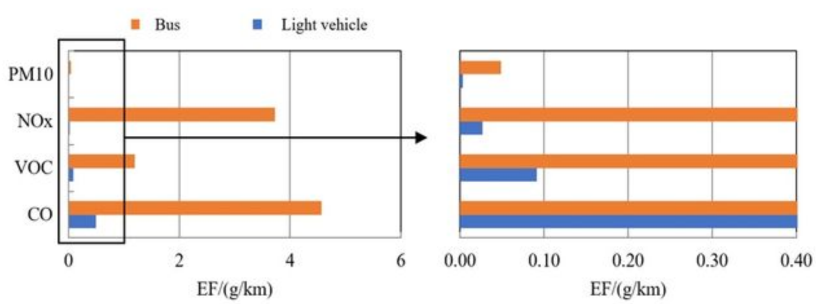
Emission factors with emission standards



(a) light gasoline vehicles with national standard V



(b) gasoline bus with national standard V



(c) CNG-fueled passenger vehicle

Figure 13

Emission factors of light gasoline vehicles with national standard V, gasoline bus with national standard V and CNG fuel passenger vehicle