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Improving urban bus emission and fuel consumption modeling by incorporating passenger load factor for real world driving

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Abstract: Vehicle Specific Power (VSP) has been increasingly used as a good indicator for the instantaneous power demand on engines for real world driving in the field of vehicle emission and fuel consumption modeling. A fixed vehicle mass is normally used in VSP calculations. However, the influence of passenger load was always been neglected. The major objective of this paper is to quantify the influence of passenger load on diesel bus emissions and fuel consumptions based on the real-world on-road emission data measured by the Portable Emission Measurement System (PEMS) on urban diesel buses in Nanjing, China. Meanwhile, analyses are conducted to investigate whether passenger load affected the accuracy of emission and fuel consumption estimations based on VSP. The results show that the influence of passenger load on emission and fuel consumption rates were related to vehicle's speed and acceleration. As for the distance-based factors, the influence of passenger load was not obvious when the buses were driving at a relative high speed. However the effects of passenger load were significant when the per-passenger factor was used. Per-passenger emission and fuel consumption factors decreased as the passenger load increased. It was also found that the influence of passenger load can be omitted in the emission and fuel consumption rate models at low and medium speed bins but has to be considered in the models for high speed and VSP bins. Otherwise it could lead to an error of up to 49%. The results from this research will improve the accuracy of urban bus emission and fuel consumption modeling and can be used to improve planning and management of city buses and thus achieve energy saving and emission reduction.

Keywords: urban diesel bus; emission; fuel consumption; passenger load; VSP; PEMS

1. Introduction

Vehicle Specific Power (VSP) is defined as the instantaneous power demand to an engine per unit mass of a vehicle. The VSP-based modeling approach is becoming more and more popular in the estimation of the vehicular emissions and fuel consumptions (FC) [1-3] especially for real world driving. VSP that contains the information of vehicle speed, acceleration, vehicle mass, and road grade is identified as an explanatory variable which is highly correlated with emissions and FC. Many models have adopted VSP as the primary parameter, because of its direct physical interpretation and strong statistical correlation with emissions and FC [4].

Frey et al. [5-6] and Zhai et al. [7] had assessed the relationship between the VSP and emission. Then they developed a VSP-based approach for emissions and FC estimation. The modal approach was used to standardize the comparisons of emission and FC rates for different vehicles and routes [8]. They also use this method to compare modal average emission and FC rates for E85 versus gasoline [9]. A VSP-based FC model was also developed for passenger cars in China [10]. Song and Yu [4] proposed a mathematical model of VSP distribution for the FC estimation. Then, based on the model, Wu et al. designed an approach for estimating FC by integrating VSP and controller area network bus technology [11]. However, these models used a fixed mass of the vehicle (often vehicle curb weight, i.e. unloaded vehicles) in their VSP calculations. The influence of passenger load variation on emission and FC estimations was neglected.

The formulas to calculate the VSP value for each type of vehicle are different. For transit diesel buses, unlike the private car, the passenger load should not be ignored for bus emissions and FC estimation because the load changes during the trip. Frey et al [5] found that the passenger load had a significant effect on FC, particularly at the middle and high-speed ranges. The increased passenger load could increase the modal average emission and FC rates. In another study, eight buses were tested with 1.0 and 2.5 tonnes load mass respectively for comparison. The average FC was increased by 4.6 ± 3.6% with 2.5 tonnes load mass compared to 1.0 tonne load mass [12]. Alam and Hatzopoulou [13] used the MOVES model to estimate the bus emissions and found that the increasing passenger load on the bus would increase tailpipe total emissions. However, for the per-passenger based emissions, the passenger load or the bus occupancy will be inversely proportional to emissions. It was also found that the influence of passenger load on emissions is also related to road grade. The steeper the road, the stronger the influence of passenger load on emissions. Nanjing is situated in a relatively flat area and thus the influence of road grade on emissions and FC is negligible in this paper. The main parameters affecting the impact of passenger load on emissions and FC are vehicle speed and acceleration. Li et al. [14] reported that passenger loads of the buses could influence buses' emissions and it is possible to obtain real-time passenger count on bus with the advanced passenger count system. So the transient bus weight could be incorporated in the emission and FC assessments. However, there is a gap in this area and there are no modal emission rates available in the literatures that take the transient bus weight into account. A constant value for bus weight was used.

In recent years, Portable Emission Measurement System (PEMS) has become an important method for vehicle real world emission research because it can obtain real time emission characteristics directly from the tailpipe for real world driving. The USEPA has put considerable emphasis on the development of PEMS for the development of emissions database for its vehicle emission model MOVES [15]. The on-board vehicle emission measurements with PEMS in China have been used to measure gaseous pollutants from buses in recent years [16-17]. Lai et al. [18] used PEMS to obtain bus emission characteristics at intersection. Zhang et al. [19] used PEMS to analyze whether alternative fuel technologies can mitigate NO_X emissions for buses. Wyatt et al. [20] investigated the impact of road grade on carbon dioxide (CO_2)

emission of a passenger car with PEMS. There is a clear need to investigate the impact of passenger load on real world driving emission and FC for city buses using PEMS and modeling methods. This forms the objective of this paper.

In this study, the correlations between emissions, FC and passenger load, vehicle speed, acceleration and VSP under real world driving conditions were evaluated using the data measured by a PEMS. The transient emissions and FC were divided into 31 bins based on vehicle speed and the VSP. A comparison was made for the emission (or FC)-VSP correlations between the VSP with and without passenger load included. The results demonstrate that the emissions and FC could be significantly underestimated when the passenger load was ignored in the VSP calculation for the prediction of emissions and FC.

2. Data and methods

2.1. Experiments using PEMS

SEMTECH-DS and SEMTECH-EFM3, manufactured by Sensors Inc., were used for this study. This PEMS uses a non-dispersive infrared (NDIR) sensor for CO and CO_2 measurement, a non-dispersive ultra-violet (NDUV) analyzer to measure NO and NO_2 separately and simultaneously, a heated flame ionization detector (FID) to analyze total hydrocarbons (THC), and an electrochemical sensor to measure O_2. A Garmin International Inc. global positioning system receiver model GPS 16-HVS was used to track the route, elevation, and ground speed of the bus under test. The vehicle activity, exhaust concentration, and emission rate data were logged on a second-by-second basis. Standard calibration gases were used to verify the accuracy of the system before each individual test, and set the target pollutants to zero [21].

The field data collection was conducted on five buses in Nanjing of China. Nanjing is a large metropolitan city with an urban population of 6.5 million and located in the east of China. The city has 5646 buses running on 369 bus routes (lines) daily in its public transport system in 2012. Majority of buses are EURO III emission compliant [22]. To represent the majority of bus fleet, five EURO III buses were selected for the field test. The typical diesel fuel used daily by the fleet with a sulfur content of 350 ppm and a specific gravity of 0.85 was employed for the test. Other detailed information of these buses is listed in Table 1. The buses were operated at normal service mode. The passengers could get on and off the bus at stops as usual.

Table 1. Buses selected for field data collection

Number	Bus line	Vehicle model	Engine model	Displacement (L)	Curb vehicle mass (kg)	Vehicle mileage traveled (*1000km)
#1	#30	NJC6104HD3	CA6DF3-24E3	6.74	9450	141
#2	#163	NJC6104HD3	CA6DF3-24E3	6.74	9450	118
#3	#100	SWB6116MG	SC8DK250Q3	8.27	10450	49
#4	#60	SWB6116MG	SC8DK250Q3	8.27	10450	91
#5	#44	XMQ6116G3	CA6DL1-26E3	7.7	11000	134

The routes travelled by the buses were showed in Figure 1. The data collection was carried out at the peak hour and off-peak hour on five working days. The weather was similar during the tests. The measurements were carried out with the bus' air conditioning system switched off.

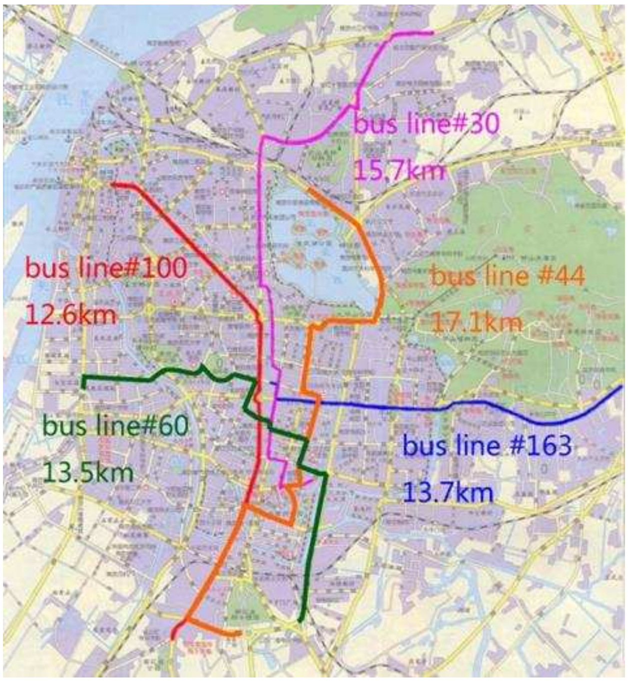


Figure 1. Experimental routes selected for field data collection

2.2. Data processing

The number of passengers getting on and off the bus at every stop has been recorded so that the real-time ridership data were obtained. The passengers were divided into six groups according to the age and gender. Fifty kilogram was taken as one basic unit of passenger load. Various coefficients were applied for six groups' passenger load calculation as shown in Table 2 [23].

Table 2. Coefficient for passenger load calculation

Male mass			Female mass		
≤6 years old	7-17 years old	≥18 years old	≤6 years old	7-17 years old	≥18 years old
0.4*50kg[a]	1.1*50kg	1.4*50kg	0.36*50kg	0.9*50kg	1.1*50kg

Note: [a.] Fifty kilogram was taken as one unit of passenger load.

2.3. Calculation formula of VSP for urban transit buses in Nanjing

Figure 2 shows the force analysis of a testing bus. According to the definition of VSP, the calculation formula can be derived as Eq. 1:

$$\mathrm{VSP}=\frac{\mathrm{Power}}{\mathrm{Mass}}=\frac{F_t v}{m}=\frac{\left(F_f+F_w+F_i+F_j\right)v}{m}$$

$$=\frac{\left[mgf\cos\alpha+0.5\rho_a C_D A\cdot\left(v+v_m\right)^2+mg\sin\alpha+\left(1+\varepsilon_i\right)\cdot ma\right]v}{m}$$

$$=v\left[g\cdot f+g\cdot\sin\alpha+\left(1+\varepsilon_i\right)\cdot a\right]+0.5\rho_a\frac{C_D A}{m}\left(v+v_m\right)^2 v \tag{1}$$

where F_t notes tractive force of the bus (N); F_f, F_w, F_i and F_j are rolling resistance, wind resistance, gradient resistance and acceleration resistance, respectively (N); v is the driving speed of the bus (m/s); m notes the total mass of this bus, including its net weight and passenger load (kg); g is the acceleration of gravity (9.807 m/s^2); f is coefficient of rolling resistance (0.00938, dimensionless); α is road grade; ρ_a is ambient air density (1.226kg/m^3 at 15 °C); C_D is drag coefficient (0.6, dimensionless); A is frontal area of the bus (2.5 width*2.8 height=7 m^2); v_m is headwind into the bus (0, m/s); ε_i is mass factor (0.1, dimensionless) and a is acceleration of the bus (m/s^2).

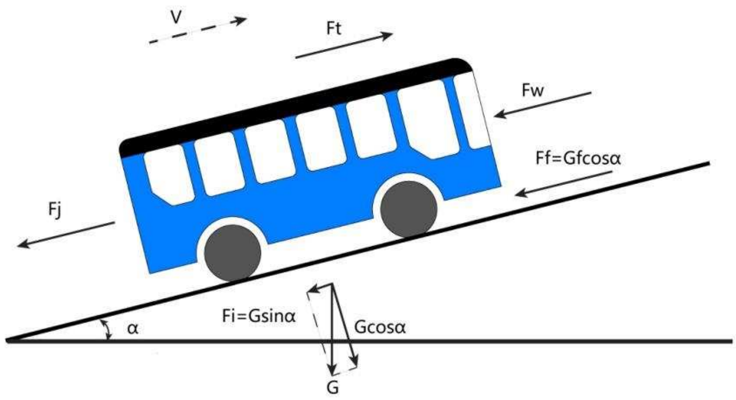


Figure 2. Force analysis for the testing bus

The coefficient of rolling resistance (f) was related to the road surface type and condition as well as the tire type and pressure [24-25]. In addition, speed shows small influence on the coefficient. In order to simplify the calculation, the coefficient value has been chosen on constant level according to the road surface and the bus tire being tested.

εi is mass factor. According to the previous study [24-25], typical values of εi for a manual transmission are 0.25 in 1st gear, 0.15 in 2nd gear, 0.10 in 3rd gear, and 0.075 in 4th gear. 0.10 was chosen for all the buses because the 3rd gear is the most commonly- used in the test and in –service driving._

The last term In Eq. 1, the load due to aerodynamic drag, $0.5\rho_a \frac{C_D A}{m}(v+v_m)^2 v$, depends on the factor (C_D*A/m) which is different for each specific vehicle model and payload [24]. By applying the values of known parameters into Eq. 1 for the testing buses, Eq. 1 is rewritten as below in Eq. 2, where m is the passenger load on the bus, which is a variable.

$$\text{VSP}=v\left(0.092+9.807\cdot\sin\alpha+1.1a\right)+\frac{2.545}{m}v^3 \tag{2}$$

The road grade in this study was assumed to be 0 as Nanjing is located in a flat area, and the elevation for the five bus lines being tested is negligible.

3. Results and discussion

A total of 65,131 sets of valid second-by-second data were obtained, including the instantaneous emissions rates of CO_2, CO, NO_X, and HC, exhaust flow rate, speed, barometric pressure, temperature and humidity. FC rates were also calculated by carbon balance method. Results were processed and evaluated by (a) influence of passenger load on emission and FC rates (g/s); (b) influence of passenger load on distance-based emission and FC factors and (c) influence of passenger load on VSP calculation and emission (or FC) estimation.

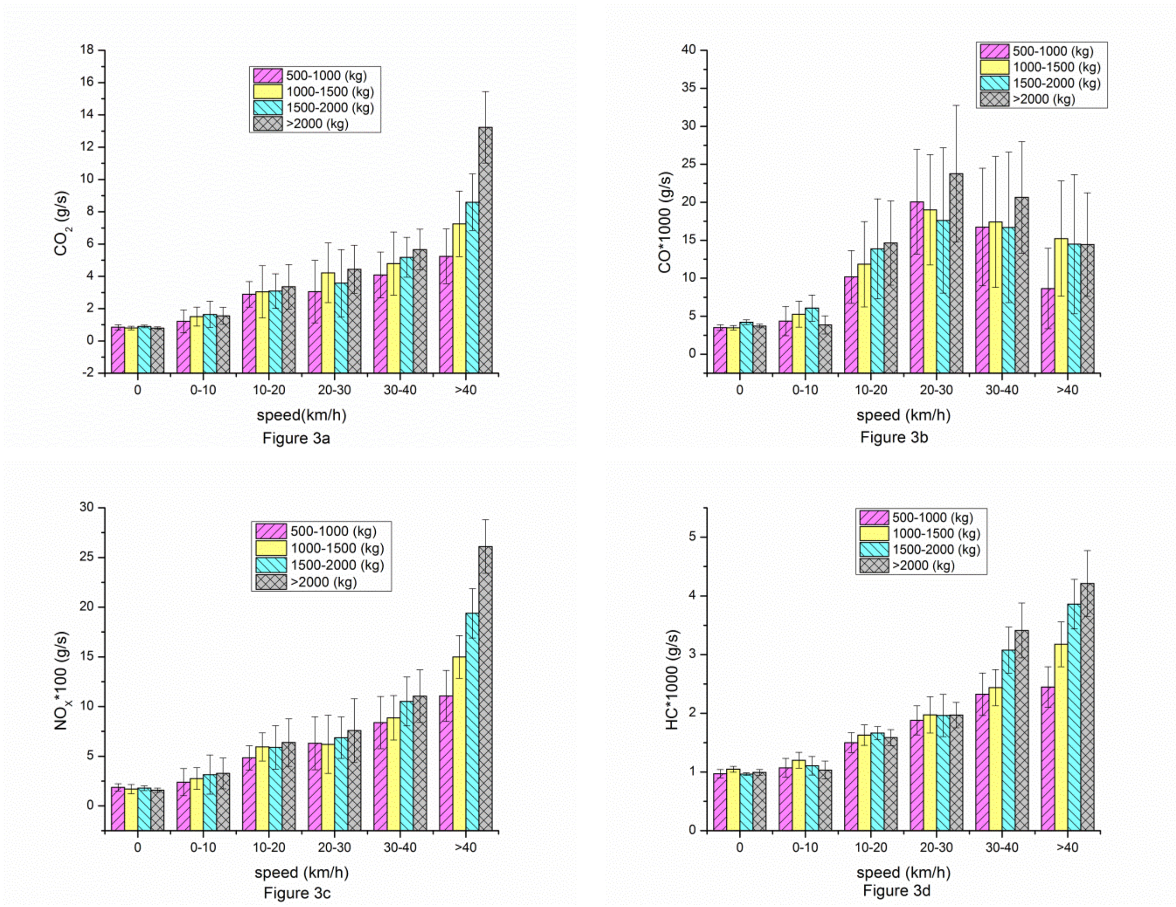
3.1. Influence of passenger load on emission and fuel consumption rates (g/s)

To assess the impact of passenger load on emission rates, the recorded passenger load values were divided into four segments (500~1000kg, 1000~1500kg, 1500~2000kg, >2000kg). The vehicle's road speed was divided into six segments in the same interval (0km/h, 0~10km/h, 10~20km/h, 20~30km/h, 30~40km/h, >40km/h). The average values of emission rates (g/s) were calculated in every different segment.

Emission rates (g/s) for CO_2, CO, NO_X and HC as a function of passenger load and speed are shown in Figure 3. Apart from CO, the impact of passenger load on the emission rates became more obvious with the increase of the speed, e.g. when the bus was driving at 40 km/h, CO2 emission rate at high load (>2000 kg) can be three times as high as that at the low load (500-100kg). The emission rates were similar in idling or low speed range.

The emission rates of the idling state should be the same for all passenger loads. However, in the previous studies [26], it was found that, during the idling, although the vehicle velocity was zero, the engine operating conditions were variable at the beginning and the end of the idling. So it may be the reason why there were few differences with different passenger loads when the vehicle speed was idling.In the low speed segments, the emission rates values is similar with different passenger loads, because speed is the control factor to emission in these segments. But in the high speed segments, the results show that the different passenger loads had a strong influence on emission rates.

The results of FC (Figure 3e) show the similar trend with CO_2. As for CO in figure 3b, the peak value appeared when the driving speed was between 20km/h and 30km/h. The passenger load did not affect CO emissions obviously in medium and high speed ranges.



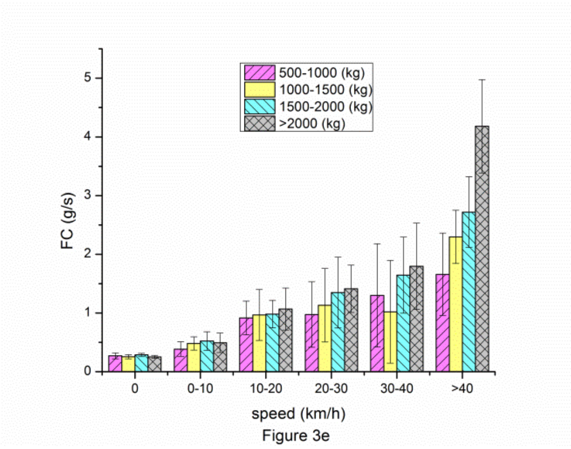
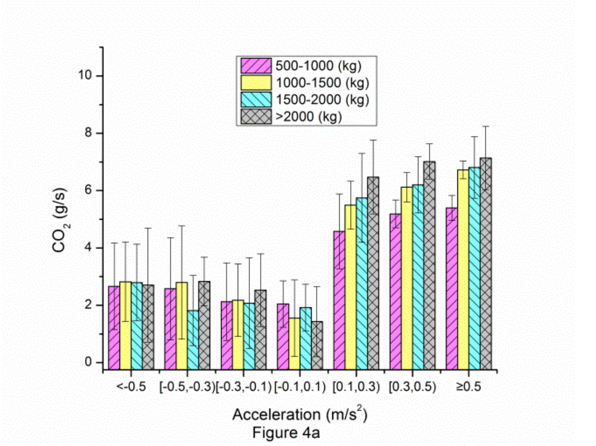
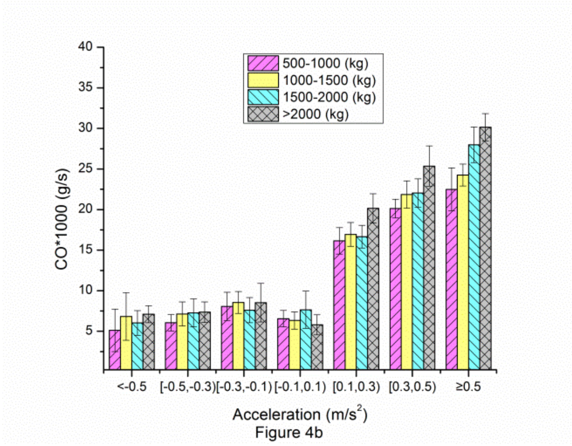
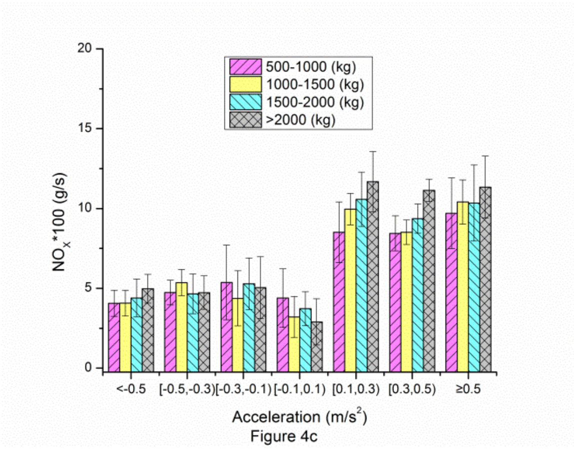


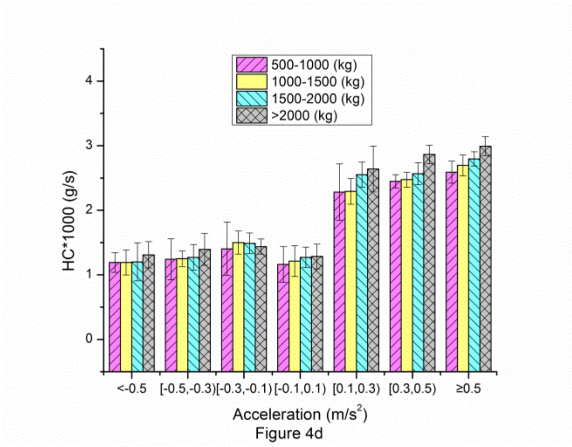
Figure 3. Emission rates (g/s) for (a) CO_2, (b) CO, (c) NO_X and (d) HC and (e) FC rates at different speed and passenger load

Using the same method, the impact of passenger load and accelerations on emission and FC rates was assessed. The passeneger load range was divided into four segments (500~1000kg, 1000~1500kg, 1500~2000kg, >2000kg). The acceleration rate was divided into seven segments (<-0.5m/s^2, -0.5~-0.3 m/s^2, -0.3~-0.1 m/s^2, -0.1~0.1 m/s^2, 0.1~0.3 m/s^2, 0.3~0.5 m/s^2, >0.5 m/s^2). It can be seen in Figure 4 that the impact of passenger load on emission and FC rates were directly affected by accelerations. The acceleration itself showed a strong influence on emissions and FC, i.e. the emissions and FC were increased significantly with increased accelerations. There was a significant increase in all emissions and FC at all load conditions when the acceleration was increased from -0.1~0.1 m/s^2 to 0.1~0.3 m/s^2). It is observed that there is a general trend that the emissions and FC were increased as the passenger load increased when the bus was in acceleration mode. Passenger load had no impact on emission and FC rates when the acceleration was low and negative values, i.e. the bus operated under deceleration or idling mode.









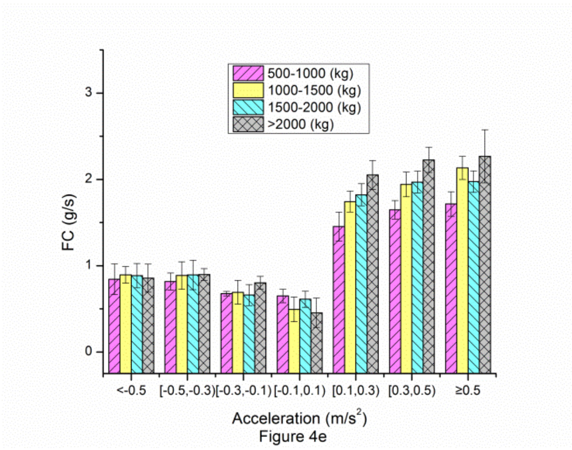


Figure 4. Emission rates (g/s) for (a) CO_2, (b) CO, (c) NO_X and (d) HC and FC rates (e) at different acceleration and passenger load

3.2. Influence of passenger load on distance-based emission and fuel consumption factors

The driving cycle of the bus line can be divided into three segments: bus stops, road junctions and links. The distance-based emission and FC factors of every link were calculated with different passenger load. Figure 5 shows the emission and FC factors as a function of the average speed and passenger load. There was a decreasing trend for emission and FC factors as the average speed increased. However, there was no clear trend for the influence of passenger load on emission and FC factors at both low and high speed.

According to previous studies [27], the emission and FC factors in the acceleration mode are the highest while the cruise mode is at the lowest level. At high speed, the average speed is the main influences to emission and FC factors. So there were almost no changes in emission and FC factors with different passenger loads. However at lower speed segments, there are significant variations of emission and FC factors in different links. Due to the many stop-go events, the average speed is lower, which leads to the higher emission and FC factors. In addition, the great changes in acceleration lead to the variations of emission and FC factors in different links. So there is also no significant trend for the influence of passenger load at low speed segments. The data should be analyzed combining with acceleration or VSP.

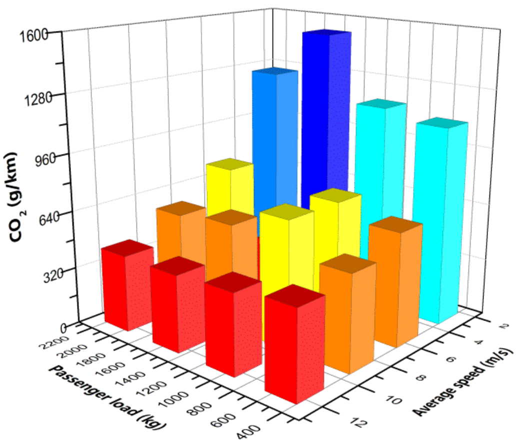


Figure 5a

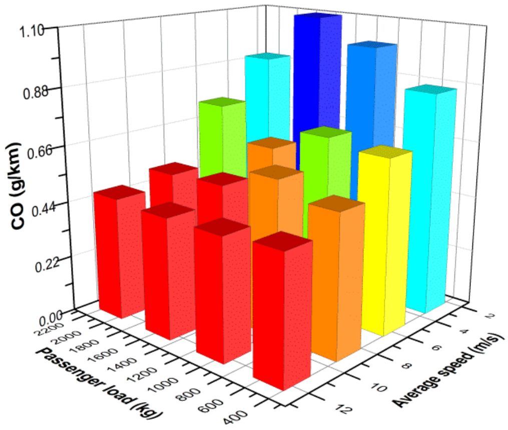


Figure 5b

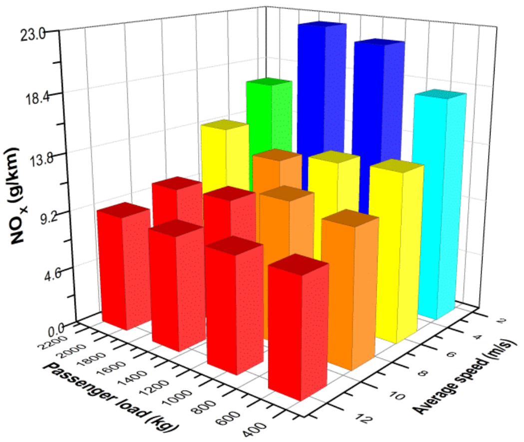


Figure 5c

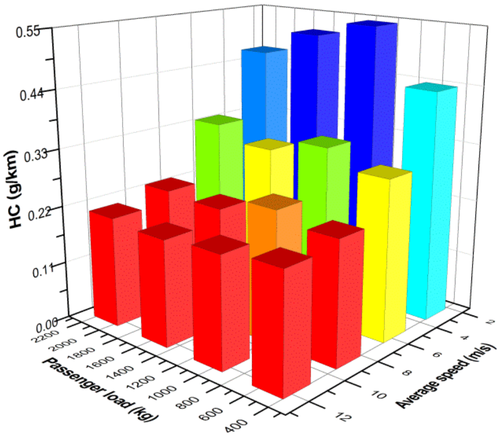


Figure 5d

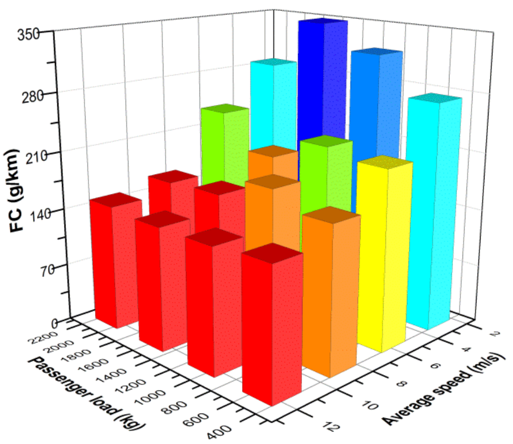


Figure 5e

Figure 5. Distance-based emission factors for (a) CO_2, (b) CO, (c) NO_X and (d) HC and (e) FC at different average speed and passenger load

Figure 6 shows the per-passenger emission and FC factors as a function of the average speed and passenger load. In order to eliminate the weight differences between different passengers, per-passenger emission and FC factors were calculated by the total emission and FC factors divided by the passenger load then multiplied by 50kg (assumed per passenger weight). The calculation formula can be derived as Eq. 3:

$$EF_p = EF/N = E/(D \times N) = \frac{3600 \times \sum e}{N \times \sum v} = \frac{3600 \times \sum e}{W/50 \times \sum v} = \frac{3600 \times \bar{e}}{W/50 \times \bar{v}} \quad (3)$$

where EF_p notes per-passenger emission factors (g/pp.km); EF is emission factors (g/km); N is the ridership; E notes the total emissions of this link (g); D is the total distance of this link (m); e is emission rate (g/s); v is the driving speed of the bus (km/h); W is the total weight of passengers (kg); $\bar{e}$ is the average emission rate (g/s); $\bar{v}$ is the average speed (km/h).

It is observed that the per-passenger emission and FC factors decreased as the bus passenger load increased. It also shows that as the vehicle's average speed increased, the per-passenger emission and FC factors decreased. By comparison of the highest emissions (the lowest passenger load and vehicle's speed) and the lowest emissions (the highest passenger load and vehicle's speed), approximately a fivefold increase can be observed for all emissions and FC.

The trend for the influence of passenger load on per-passenger factors is different from total factors. At higher speed segments, there were no significant changes of emission and FC factors with different passenger loads. So according to Eq.3, the total weight of passengers shows significant effects on the per-passenger emission and FC factors. While at lower speed segments, even if the variations in acceleration lead to the differences of emission and FC factors in different links, passenger load also shows obvious effects when the emission and fuel consumption are calculated on per-passenger basis.

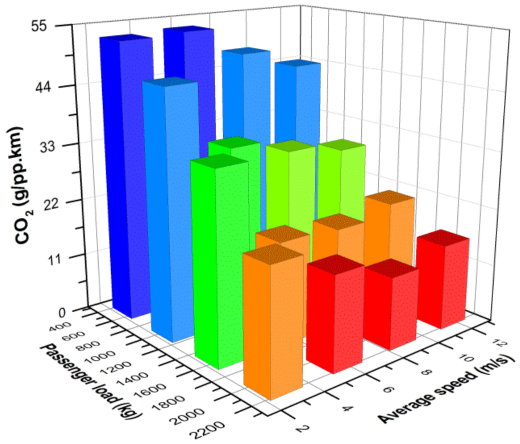


Figure 6a

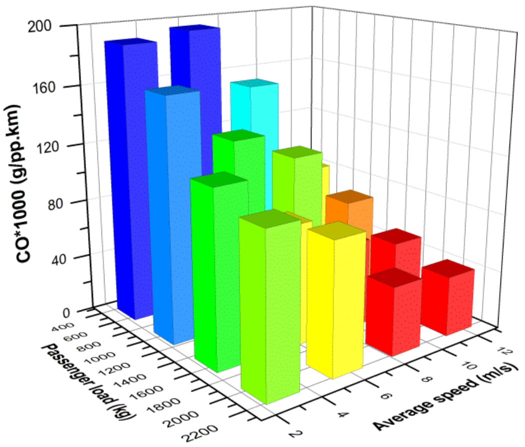


Figure 6b

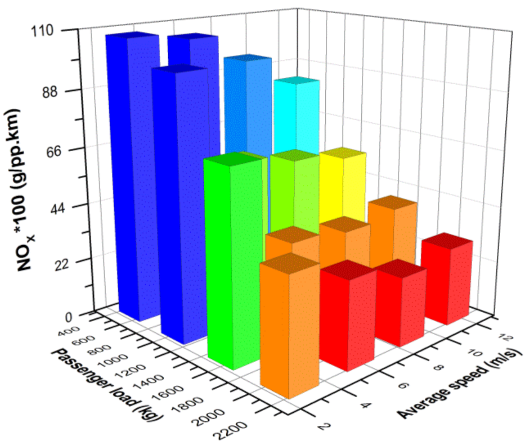


Figure 6c

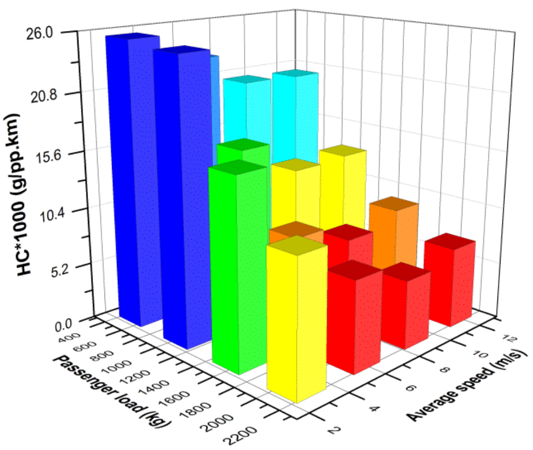


Figure 6d

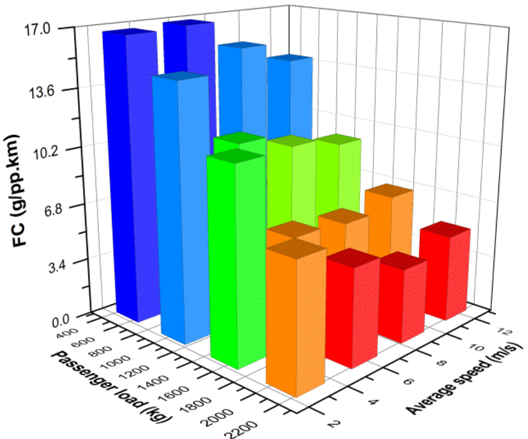


Figure 6e

Figure 6. Per-passenger emission factors [a] (based on distance) for (a) CO_2, (b) CO, (c) NO_X and (d) HC and FC factors (g/pp.km) at different average speed and passenger load

Note: [a] Per-passenger emission factors are calculated by total emission factors dividing passenger load then multiplied by 50kg.

3.3. Comparison of correlations between VSP, Speed and emissions (or fuel consumption) with and without passenger load

The analysis above showed that the passenger load has significant impact on emissions and FC. As the emissions and FC are often predicted by the VSP based modelling methods, it is therefore essential to quantify the effect of passenger load on VSP based models. To do this, the emissions and FC were firstly analyzed against the VSP using the bin method.

Based on the real-world driving speed and VSP values of the test buses, a total of 31 operating bins are defined. Apart from idle which is defined in terms of speed alone, the remaining 30 bins are defined in terms of VSP within three speed ranges. Each bin is identified by a numeric label, which is shown in Table 3.

Table 3. Method of dividing operate bins of test buses

speed(km/h) / VSP(kw/t)	0	(0,20]	(20,40]	>40
<-6		Bin101	Bin 201	Bin 301
[-6,-3)		Bin 102	Bin 202	Bin 302
[-3,-1)		Bin 103	Bin 203	Bin 303
[-1,0]		Bin 104	Bin 204	Bin 304
(0,1]	Bin0	Bin 105	Bin 205	Bin 305
(1,2]		Bin 106	Bin 206	Bin 306
(2,4]		Bin 107	Bin 207	Bin 307
(4,6]		Bin 108	Bin 208	Bin 308
(6,8]		Bin 109	Bin 209	Bin 309
(8,10]		Bin 110	Bin 210	Bin 310

Figure 7 shows the emission and FC rates of 31 VSP bins. The influence of passenger load was taken into consideration when the VSP was calculated. The average value of emission and FC rates for each bin was calculated and the estimation modals were established.

It can be seen from Figure 7, in the same range of speed, emissions and FC generally rose with VSP increasing. In addition, in the same range of VSP, emissions and FC show obvious differences among different speeds. When the bus operates at idle mode, bus emissions and FC are at lowest level. Apart from CO, emissions and FC increased with the rising of speed. However, there was a decreasing trend for CO when the bus was driving in a high speed range.

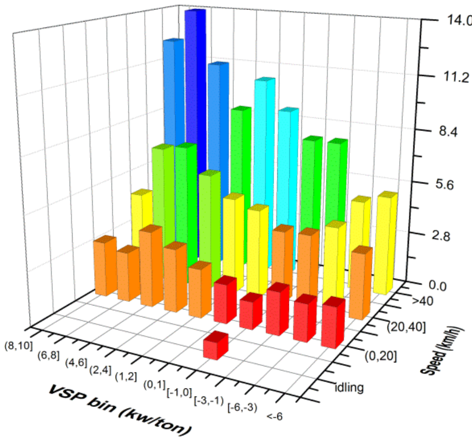


Figure 7a

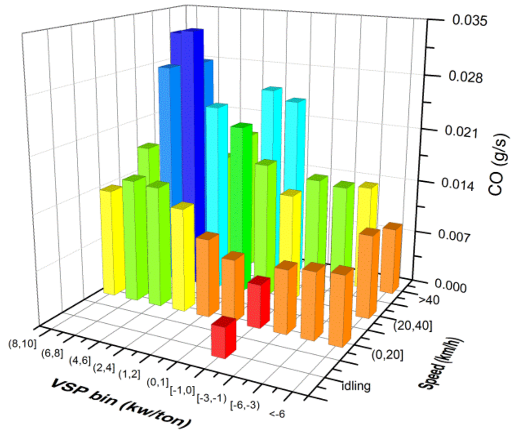


Figure 7b

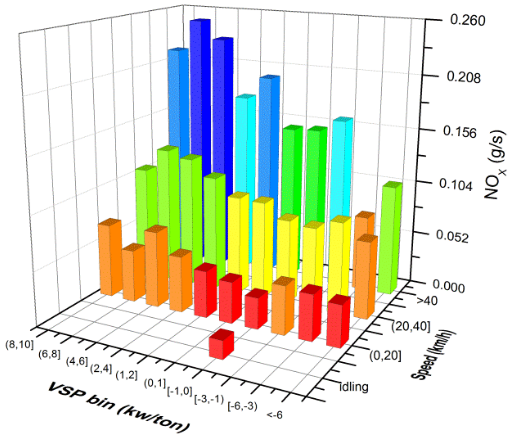


Figure 7c

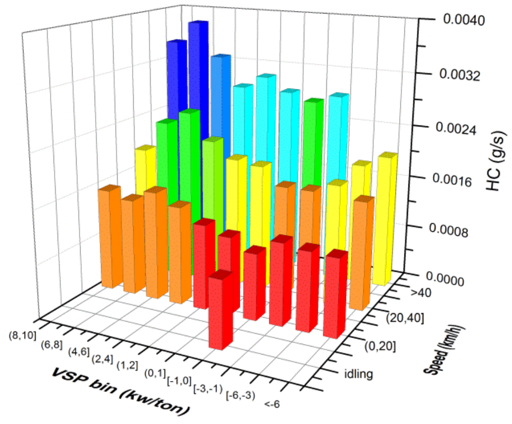


Figure 7d

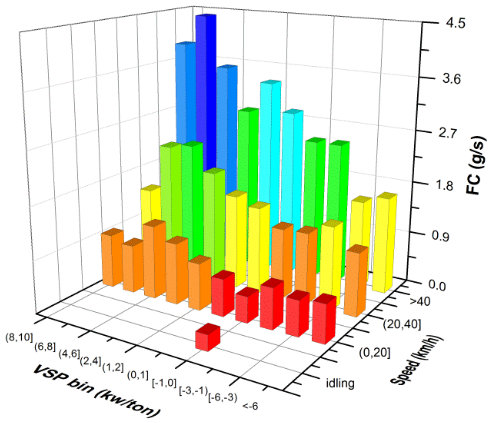


Figure 7e

Figure 7. Emission rates (g/s) for (a) CO_2, (b) CO, (c) NO_X and (d) HC and FC rate (g/s) in every operate bin of different speed and VSP

In order to compare the emission (or FC) -VSP correlation with and without passenger load included, the passenger load was ignored in the second calculation. The VSP bins were calculated using a fixed vehicle mass with no passenger load variations included. In that way, the largest relative percentage decrease in weight could be 41.2%.

The emissions and FC were then calculated against each bin. The two calculated emissions and FC for each bin were compared. Table 4 lists the relative changes in emissions and FC from two calculations. The negative values indicate that emissions and FC could be underestimated without passenger load included. Positive value means overestimated emissions and FC without effect of passenger load. The results show that without passenger load included, the emissions and FC would be underestimated, especially at high speed and high VSP ranges. However, there are still some positive numbers in this table. In addition, larger positive values appear when VSP is ranging from 4 kw/ton to 6kw/ton. The possible reason is that when VSP is calculated without passenger load included, an error occurs and leads to the change of grouping, which causes the variation of average values in these bins.

The italic font is used in Table 4 to highlight the significant differences in the estimated emissions and FC between the two methods. The results show that in the low speed range, the significant deviation by the model without incorporating the passenger load values occurred for the high VSP values/bins. In the medium to high speed ranges, the deviation occurred not only for the hush accelerations (high value positive VSP bins but also in the sharp decelerations (high value negative VSP bins). In general, more deviations in emission and FC estimations between two methods were seen when the vehicle speed was at medium to high ranges. Hence it can be concluded that the passenger load should not be omitted in the emission and FC models, particularly for high speed and high VSP bins, otherwise there will be large errors in the estimation.

Table 4. Percent differences in emission and FC rates estimates without effect of weight case compared to with effect of weight case

Bins	Description of every bin		CO_2	CO	NO_X	HC	FC
	VSP(kw/t)	speed(km/h)	(g/s)	(g/s)	(g/s)	(g/s)	(g/s)
Bin0	Idling		0%[a]	0%	0%	0%	0%
Bin101	<-6	（0,20]	0%	7%	4%	1%	0%
Bin102	[-6,-3]		0%	0%	0%	0%	0%
Bin103	[-3,-1)		4%	8%	9%	3%	4%
Bin104	[-1,0]		4%	4%	3%	9%	4%
Bin105	(0,1]		1%	3%	8%	3%	1%
Bin106	(1,2]		-2%	-2%	8%	-1%	-2%
Bin107	(2,4]		-2%	1%	1%	-2%	-2%
Bin108	(4,6]		-27%	-25%	-18%	-11%	-27%
Bin109	(6,8]		13%	12%	-7%	-4%	13%
Bin110	(8,10]		-28%	11%	12%	-10%	-28%
Bin201	<-6	(20,40]	-10%	-10%	-4%	-3%	-10%
Bin202	[-6,-3]		1%	-1%	-1%	0%	1%
Bin203	[-3,-1)		-8%	-8%	-3%	-4%	-8%

Bin204	[-1,0]		-1%	-5%	2%	2%	-1%
Bin205	(0,1]		-9%	-9%	-8%	-5%	-9%
Bin206	(1,2]		9%	6%	6%	1%	9%
Bin207	(2,4]		-1%	0%	-3%	-2%	-1%
Bin208	(4,6]		12%	11%	8%	8%	12%
Bin209	(6,8]		2%	8%	3%	2%	2%
Bin210	(8,10]		-7%	-11%	-5%	-4%	-7%
Bin301	<-6	＞40	-17%	-15%	-5%	-13%	-17%
Bin302	[-6,-3]		-33%	-27%	-31%	-22%	-33%
Bin303	[-3,-1)		9%	-5%	8%	9%	9%
Bin304	[-1,0]		1%	-4%	4%	3%	1%
Bin305	(0,1]		-2%	-8%	-4%	-2%	-2%
Bin306	(1,2]		6%	4%	-2%	7%	6%
Bin307	(2,4]		-1%	-15%	2%	-2%	-2%
Bin308	(4,6]		8%	11%	4%	5%	8%
Bin309	(6,8]		-16%	-12%	-14%	-8%	-16%
Bin310	(8,10]		-47%	-49%	-15%	-26%	-47%

Note: [a.] The value is calculated by the formula: [B (without effect of weight case) –A (with effect of weight case)]/A *100%.

4. Conclusions

This paper examined the impact of passenger load, vehicle's speed and accelerations on the emission and FC rates, distanced based emission and FC factors and per-passenger emission and FC factors of city buses based on emission data measured by the PEMS under real world driving in Nanjing China. Tailpipe CO_2, CO, NO_X and HC emissions were measured and recorded from five bus lines, along with passenger load information. The results show that:

1. For emission and FC rates, the influence of passenger load on the emission rates of CO_2, NO_X and HC became significant when the buses were travelling at the relatively high speed (30 km/h or above) while no obvious impact of passenger load was observed when the vehicle speed was below 30 km/h. Passenger load had no impact on CO emissions. Accelerations could have remarkable impacts on emission and FC rates once the vehicle's acceleration rate was above 0.1 m/s. The impact of passenger load on emissions was also clearly shown when the acceleration rate was above 0.1 m/s.
2. For distance-based emission and FC factors, there were no clear trends on the influence of passenger load on the distance based emission and FC factors at both low and high vehicle's speed. The distanced based emission and FC factors decreased as the vehicle's speed increased. This is well aligned with the knowledge that the congested traffic produced more emissions and FC while the free flow traffic give rise to lower emissions and FC.
3. The per-passenger emission and FC factors showed an inverse correlation with passenger load, i.e. as the passenger load increased, per-passenger factors decreased. This indicated that when the bus

is running on low load (low occupancy), the per-passenger emission and FC factors may not lower than private cars. Buses' emissions and FC could be as bad as passenger cars on a per passenger basis. For example, the HC per-passenger emission factor of one gasoline car ranged from 0.01 g/pp.km to 0.04 g/pp.km in Nanjing, China [27]. However, the HC per-passenger emission factors for buses were higher than 0.02 g/pp.km when there were few passengers. Thus it can be seen that the reasonable planning and management for transit buses is important for emission reduction and energy saving. The punctuality and reliability of transit buses will help reduce bunching of buses and help the passenger load to be evenly distributed in the every bus of bus lines.

4. The comparison of the emission and FC estimations by VSP between with and without passenger load included showed that the passenger load cannot be omitted in the models for high speed and high VSP bins. However, it could be omitted for low and medium speed and VSP bins.
5. It needs to be stated that the finding from this study is suitable for cities in flat areas as the road grade where the data was collected is negligible. In the future, the effects of road grade should be incorporated along with passenger load factor.
6. Though a large amount of data (65,131) had been recorded in this study, limited buses (five buses on five bus lines) were used. The conclusions may have their limitations. The analysis method should be extended to other types of buses and various passenger loads when the PEMS data are available to confirm the trends uncovered in the samples used in this study.

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