Vehicular modal emission and fuel consumption factors in Hong Kong

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Abstract

This paper reports on the analysis of vehicular exhaust emissions and fuel consumption conducted using modal approach. The four standard driving modes are idling, accelerating, cruising and decelerating. Data were collected using instrumented test vehicles traveling many times through the urban areas of Hong Kong. Emission and fuel consumption factors were derived for each driving mode. The pollutants of interest are CO, HC, NO_x and particulates. The behaviours of different pollutants and fuel consumption for particular driving mode were studied. Finally, the application of the modal emission factors was discussed.

1 Introduction

It is well researched that vehicle emissions and fuel consumption are largely dependent on engine operating conditions. In particular, the emission time profile is correlated to the sequence of typical driving variables such as speed and acceleration. The latter correlation can be described through statistical analysis only when very large data population exists [1]. With a smaller sample size, the identification of fuel consumed and emissions generated by particular driving modes (i.e. idling, accelerating, cruising and decelerating) can be a very useful tool in improving the assessment of vehicular emissions impact on air quality [2].

Modal analysis of vehicle emissions and the corresponding emission factors obtained permit important applications [2]. It is well known that the average emission factors are usually available as global values referred to standard

driving cycles and parameterized in terms of their mean speed. These factors may not suitable for describing emission situations where only particular driving modes are involved. Modal emission factors allow for a greater detail assessing emissions in these particular situations.

In junction analysis, in order to take into account of the junction-imposed spatial variability of emissions, researchers modeled the emissions and fuel consumption from vehicles operating at four different modes, namely, cruising, decelerating, idling and accelerating [3-13]. Emissions and fuel consumption were determined using emission and fuel consumption rates disaggregated by operating mode, which can be easily combined to be the driving sequence of individual vehicle.

This study analyzes the emissions and fuel consumption data collected from 4 instrumented test vehicles driving many times in the urban area of Hong Kong. Modal and average emission and fuel consumption factors were derived. The behaviours of different pollutants and fuel consumption for particular driving mode were studied. Finally, the applicability of the modal emission factors was discussed.

2. Data collection

The data were collected at the morning peak period ranging from 8:00 a.m. to 11:00 a.m. and the off peak period ranging from 2:00 p.m. to 5:00 p.m. in the months from March to June 1998 during calm and dry weather conditions.

Four instrumented vehicles with different types, sizes and weights were employed in the collection of speed, emissions and fuel consumption data. They are one petrol van, one diesel van, one petrol private car and one diesel bus. The specifications of these test vehicles are shown in Table 1.

Table 1. Specification of test vehicles

	Petrol Private Car	Petrol Van	Diesel Van	Bus
Vehicle Type	Nissan Sunny	Nissan Urvan	Toyota Hiace	Gardner Double Decked Bus
Engine Capacity	1498 cc	1952 cc	2799 cc	18840 cc
Fuel Type	Gasoline	Gasoline	Diesel	Diesel

A study found that fuel consumption and emission depended on whether they were measured at steady speed or with actual driving pattern [14]. It was found that emissions measured on actual speed driving cycles are generally higher than those measured on the steady speed driving cycles. In order to capture various driving conditions, the test vehicles were driven many times in the urban areas of Hong Kong. Speed-time data, fuel consumption rates and exhaust emission rates were collected.

Engine speed and the transmission shaft rotating speed were measured by an infrared photoelectric sensor. Incorporating with a PICO acquisition software, the speed data were collected into a computer. Vehicle speed was calculated from the shaft speed by a simple equation.

An Econotest fuel flow meter was connected in the fuel supply pipe to obtain the instantaneous fuel consumption. However, due to some operational difficulties, fuel consumption data were not collected for bus test run.

Instantaneous concentration of CO, CO_2, NO_x, HC and O_2 were measured by a Flux-2000 gas-analyzer, which can analyze up to 5 type of gas at the same time. The exhaust gas analyzer was calibrated with standard gases before the measurements.

According to the Environmental Protection Department of Hong Kong, diesel vehicles are responsible for an absolute majority of the vehicular particulate emissions, so particulate emission measurements in terms of smoke intensities were performed, in particular, for diesel vehicles. Instantaneous smoke intensity data from diesel vehicles were collected by a smoke meter. The smoke meter was calibrated before performing the test runs.

The arrangement of the on-board measurement system is outlined in Figure 1. The gas filter connected with the smoke meter is used to filter out water vapour from the exhaust gas while the filter connected with the gas analyzer is used to filter out water vapour and particulates in diesel vehicles.

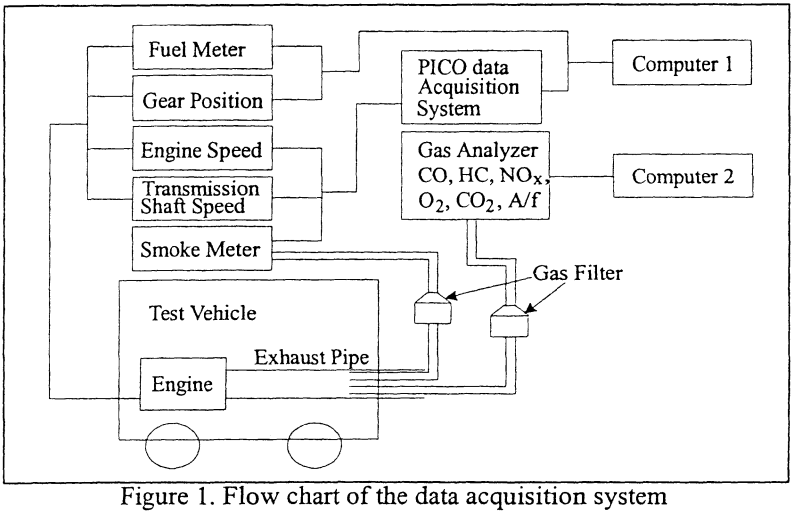

Figure 1. Flow chart of the data acquisition system

There are a total of four sets of instantaneous speed, emissions and fuel consumption data by vehicle types, which are the diesel van, the petrol passenger car, the petrol van and the diesel bus. These data, which were collected at 1-second resolution, form a basis for emission and fuel consumption analysis of this study.

3. Results and discussions

With the acquired instantaneous speed data, acceleration rates were calculated using the method of central difference. The corresponding emissions and fuel consumption data were then classified according to various driving modes. The four standard driving modes were defined as follows:

(a) Idling mode: Zero speed.
(b) Acceleration mode: Portions having positive incremental speed changes of more than 0.1 m/s^2.
(c) Cruising mode: Portions having absolute incremental speed changes of less than or equal to 0.1 m/s^2.
(d) Deceleration mode: Portions having negative incremental speed changes of more than 0.1 m/s^2.

The value of 0.1 m/s^2 acceleration rate has been used extensively by other researchers in defining driving modes [4-7]. For each vehicle, the emission and fuel consumption data for each driving mode were averaged to give the modal emission and fuel consumption factors in the unit of mg/s. The average and modal emission factors for each test vehicle were shown in Table 2. The average emission and fuel consumption factors were calculated as mean values over all the test runs for each vehicle.

3.1 Average emission factors

The results of the average emission factors derived from the available data are generally consistent with the previous research works [1,2]. Diesel vehicles (i.e. Diesel van and bus) have comparatively higher CO and NO_x emissions than HC and particulate emissions. Whereas gasoline vehicles (i.e. the petrol van and the private car) are shown to emit significantly more CO than NO_x and HC.

Comparing emissions from the vans, the differences between emissions from diesel and gasoline vehicles can be observed. It is shown that the diesel van has significantly lower CO, HC as well as NO_x emissions but higher fuel consumption factor than those of the petrol van.

There are notable differences between the emissions of the bus and the diesel van, which arising mainly from the engine capacity of the vehicle. The bus, which is the largest and heaviest among the four test vehicles, having the largest engine capacity, consuming more energy, with no doubt that having rather high emissions factors. The HC, NO_x and particulate emissions from the bus give the highest values among all the test vehicles.

For the gasoline vehicles, emissions from the petrol van are shown to be significantly higher than that from the private car. It is due to not only the effect of the catalytic converter but also the effect of engine capacity. The petrol van has a larger engine capacity, the emission factors and fuel consumption thus are higher than that of the private car.

Table 2. Fuel consumption and emission factors of various pollutants

	Emission factors (mg/s)					Average speed (km/h)
	CO	HC	NO_x	PM	Fuel	
verage	4.35	0.35	0.35	--	22.67	24.00
cceleration	4.83	0.48	0.42	--	35.83	26.15
ruising	4.63	0.40	0.37	--	21.29	30.78
eceleration	4.69	0.45	0.39	--	13.90	27.60
dling	1.58	0.24	0.08	--	9.23	--
verage	14.03	1.70	1.74	--	46.54	27.47
cceleration	15.97	1.80	2.01	--	58.71	31.15
ruising	14.21	1.62	1.81	--	49.82	30.16
eceleration	15.87	1.73	2.00	--	47.61	31.80
dling	8.14	1.45	0.58	--	11.54	--
verage	1.09	0.24	0.45	0.04	51.36	23.19
cceleration	1.41	0.21	0.49	0.03	55.14	23.83
ruising	1.33	0.20	0.43	0.03	51.60	22.68
eceleration	1.06	0.16	0.46	0.02	47.01	18.54
dling	0.60	0.09	0.22	0.01	13.90	--
verage	9.95	1.49	9.98	0.36	--	12.22
cceleration	13.44	1.92	12.69	0.80	--	18.37
ruising	7.65	1.40	9.08	0.15	--	9.17
eceleration	10.70	1.56	10.63	0.29	--	16.43
dling	6.80	0.90	4.04	0.05	--	--

3.2 Modal emission factors

In terms of mass of pollutants emitted per second, Table 2 shows that the acceleration and deceleration modes basically have higher emissions for various pollutants than the cruising and idling modes, which agrees with the results from Matzoros and Van Vliet [9-11] as well as those from Mole [12]. They revealed that transient modes (i.e. deceleration and acceleration) were generally more polluting than steady speed modes (i.e. cruising and idling).

In fact, the vehicle exhaust pollutants being investigated in this study mainly come from the incomplete combustion of the fuel consumed. During acceleration, the engine needs more fuel to generate enough power to accelerate the vehicle, thus increases the amount of pollutants emitted. Therefore, acceleration mode is found to be the most polluting and fuel consuming driving mode among the four standard driving modes (Table 2). However, during cruising mode, fuel is used to maintain the rotation of engine at a certain speed level so that lower fuel consumption and emissions than those of the acceleration mode are observed.

During deceleration, vehicles are basically traveled in its inertial forces gained during the precedent acceleration and cruising modes, so little fuel is needed. However, the fuel flowing rate cannot be stopped immediately when acceleration or cruising mode changed to deceleration mode suddenly. Excess fuel thus continues to flow at the starting few seconds of the deceleration modes. Especially for hard acceleration/deceleration changes, the induced fuel consumption and emissions are more significant [15].

For idling mode, fuel is used to maintain the operation of the engine. Therefore, the fuel consumption and emissions are significantly smaller than those of the other driving modes.

3.3 Application of modal emission factors

The average emission factors are usually parameterized in terms of the corresponding average speed. However, emissions may differ under approximately the same average speed, which may arise from the variations of the proportions of different driving modes. Therefore, it is not suitable for use in some situation [2]. For example, in urban intersection emission analysis, some researchers [9-11] have criticized on this approach that ignored the junction-imposed spatial variability. Under these situations, the modal emission factors are applicable. Total pollutant emissions can be calculated by multiplying the modal emissions factors with the time spent on the corresponding driving mode.

Moreover, the modal emission factors have potential applicability for evaluating global emissions for any driving cycle, without expensive emission and fuel consumption measurements. The mass of pollutant emissions per unit distance traveled E can be calculated by the following equation.

$$E = (t_a f_a + t_c f_c + t_d f_d + t_i f_i)(3600/V) \quad (1)$$

where t_a, t_c, t_d and t_i are the time proportions of accelerating, cruising, decelerating as well as idling modes respectively. f_a, f_c, f_d and f_i are the corresponding modal emission factors (g/s). V is the cycle average speed (km/h). Due to the variations over the average speed and acceleration rate of the corresponding driving mode [1], the modal emission factors for each driving mode have to be calibrated before they can be applied to Eqn. (1).

Table 3. Predicted emissions and fuel consumption for Hong Kong driving cycle

	Total Emissions (g/km)				Fuel Consumption (g/km)
	CO	HC	NO_x	PM	
Petrol Private Car	8.69	0.91	0.70	--	45.83
Petrol Van	30.88	3.83	3.56	--	92.30
Diesel Van	2.70	0.49	0.91	0.07	94.63
Bus	23.21	3.35	20.94	0.81	--

An example of estimating pollutant emissions of the driving cycle for Hong Kong is shown in Table 3. The Hong Kong driving cycle has duration of 1471s, total trip length of 6.33 km and average cycle speed of 15.48 km/h. The cycle consists of 29.98% acceleration, 9.8% cruising, 28.51% deceleration and 31.71% idling [16]. The emissions and fuel consumption shown in Table 3 are estimated by Eqn. (1) in terms of gram per kilometer traveled. The modal emission factors for different driving modes have been calibrated according to the average speed and acceleration rate of the corresponding driving mode.

4. Conclusion

Four test vehicles were employed to travel many times in the urban areas of Hong Kong to collect emissions and fuel consumption data. Average emission and fuel consumption factors calculated as average emission and fuel consumption rates over all the test runs were derived. The results were found to be consistent with previous research works.

Modal emission and fuel consumption factors for each standard driving mode (i.e. accelerating, cruising, decelerating and idling) were derived. It was found that transient driving modes (i.e. accelerating and decelerating) were significantly more polluting than steady speed driving modes (i.e. cruising and idling). The accelerating mode was found to be the most polluting and fuel consuming among the four standard driving modes.

Finally, the modal emission factors were proposed to use in urban intersection emission analysis and global emission evaluation of driving cycles.

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