MEASUREMENTS OF EMISSION FACTORS AND FUEL CONSUMPTION FOR MOTORCYCLES ON A CHASSIS DYNAMOMETER BASED ON A LOCALIZED DRIVING CYCLE

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Abstract

A localized driving cycle for motorcycles has been developed for Hanoi, Vietnam after extensive road tests. The driving cycle known as the HMDC driving cycle (Hanoi Motorcycle Driving Cycle), takes into account the road infrastructure, traffic patterns and driver's behavior in the Hanoi metropolitan area. The driving cycle developed from time - speed data of 343 driving trips has 1 250 seconds in length and 7 067 meters in distance with a maximum speed and an average speed of 39.4 and 20.4 km/h, respectively. The developed HMDC driving cycle together with the European driving cycle (ECE R40) was then implemented on new/in-use selected motorcycles using a chassis dynamometer, from which the CO, THC, CO_2, NO_x emission factors and fuel consumption were obtained. The emission factors of THC, CO, CO_2 and fuel consumption obtained during HMDC are comparable with those during ECE R40 but it is 66.7% different with NO_x emission factor.

Keywords: Driving cycle development, Exhaust emission factors, Fuel consumption, Motorcycle emissions

Introduction

Motorcycles are the dominant means of transport in Vietnam, especially in big cities where they comprise of 95.9% of total transport vehicles [1]. The number of motorcycles in Hanoi in 2009 was estimated at 2.0 million, accounting for 92.6% of the vehicle fleet; whereas the total number of motorcycles in Vietnam was 27 million [2].

Although in Vietnam Euro2 emission standard has been in effect for new motorcycles since July 1, 2007, the majority of motorcycles currently in circulation were produced prior to this date when their emissions were not regulated. The poor condition of traffic infrastructure combined with almost non-existence of traffic management has culminated in increasing heavily congested urban traffic. Consequently, motorcycles present not only traffic problems, but also contribute significantly to air pollution in urban areas. This fact has been specifically pointed out by EMBARQ, World Resources Institute in a report entitled "Measuring the Invisible: Quantifying the Emissions Reductions from Transport Solution, Hanoi Case Study" [3]. As can be seen in Figure 1 the contribution to CO emission from motorcycles alone in 2005 was 79%.

Therefore, it is imperative to reduce the exhaust emissions from motorcycles if Vietnam wants to improve the air quality. To accurately quantify the emissions from the motorcycles, it is crucial that the driving cycle, under which the emissions have to comply, reflects normal driving conditions as much as possible. In order to have a realistic picture of total exhaust emissions from motorcycles from which strategy for reduction of pollutant emissions from motorcycles can be implemented, emission factors of motorcycles must be accurate.

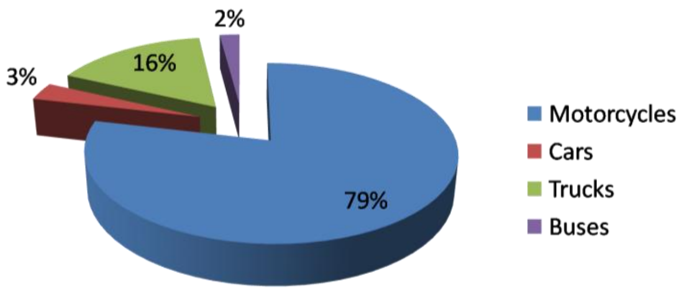

Figure 1. Contribution to CO emission from different on-road mobile sources

A number of methods can be used to obtain an emission factor database such as: Using emission factors from the country that has similar transport system; using emission models, usually instantaneous emission models; and developing a localized driving cycle and implementing it on test motorcycles mounted on rollers. The first method gives biggest uncertainties due to differences in traffic conditions, traffic management, vehicle types, driver's behavior, and etc., which could result in large discrepancy in emission factors. The second method is based on a long term schedule in order to have good database of vehicle fleets in conjunction with instantaneous emission measurements. The last method unequivocally is the best alternative at this time for Vietnam [4] [5].

Currently there exists a number of driving cycles for vehicles worldwide, which were developed under specific driving characteristics such as ECE cycle (Europe), the U.S. Federal Test Procedure (USA), Hong Kong cycle (HongKong), 10-15 mode (Japan), and etc. Since the driving characteristics are inherently different from one area to another, even within the same city, it is unrealistic to expect accurate emissions prediction by using a driving cycle developed somewhere else for a specific city [6,7,8,9]. As a case in point, Table 1 shows the discrepancy in emission factors between ECE driving cycle and Kaohsiung driving cycle (KHM) when used in Kaohsiung city, Taiwan [10].

Table 1. Emission Factors and Fuel Consumption of 4-Stroke Motorcycles During ECE and KHM Cycles [10]

Type	Driving Cycle	CO(g/km)	HC(g/km)	NO_x(g/km)	CO_2(g/km)	Fuel Consumption (*l*/km)
3 New Motorcycles	ECE	1.17±0.69	0.29±0.13	0.15±0.06	59.5±4.7	0.026±0.0026
	KHM	2.28±0.98	0.48±0.25	0.17±0.04	61.3±3.6	0.028±0.0026
	KHM/ECE	1.95	1.66	1.13	1.03	1.08
6 In-Used Motorcycles	ECE	5.61±4.29	0.58±0.20	0.18±0.07	54.7±4.3	0.028±0.0028
	KHM	7.41±4.90	0.79±0.21	0.26±0.06	55.9±5.2	0.030±0.0030
	KHM/ECE	1.32	1.36	1.44	1.02	1.07

As seen in Table 1, ECE driving cycle underestimates up to 95% the emission factors of new motorcycles, and up to 44% for in-used motorcycles in Kaohsiung city. Therefore, development of local real world driving cycle is important for exhaust emissions and fuel consumption measurement, traffic management, vehicle and emission control strategy, energy consumption and motorcycle industry development.

The driving cycles of vehicles have been developed under specific driving characteristics. Some are based on on-road driving data records such as Kaohsiung driving cycle (KHM), the U.S. Federal Test Procedure (FTP 75) and Hong Kong driving cycles [9,10,11], while others use models or polygonal driving cycles [12] such as the Japanese cycle [13] and European driving cycle (ECE).

In Vietnam, currently there is no existing local driving cycle for motorcycles, and in its absence the emission approval tests are based on ECE driving cycles instead. Accordingly, the objective of this research is to develop a local motorcycle driving cycle for Hanoi based solely on Hanoi urban driving characteristics such as traffic conditions, idle, cruising, acceleration proportions, average speed and acceleration. From the developed Hanoi driving cycle the emission factors of CO, THC, NO_x and CO_2 for 4-stroke motorcycles are obtained. Once the driving cycle is implemented successfully in Hanoi, it is anticipated that it would serve as an example for other urban areas in Vietnam to follow in developing their own local driving cycles.

There are a number of methods for developing a driving cycle from an enormously large amount of time-speed data. In developing their driving cycle Kent, et al. (1978) [7] used only the average speed, the root mean square acceleration and the idle time proportion. Tong, et al. (1999) [9] developed a standard driving cycle for urban areas of Hong Kong using nine parameters such as average speed, average acceleration, average deceleration, mean length of a driving period, time proportions of driving modes. On the other hand Esteves-Booth, et al. (2001) developed a driving cycle for Edinburgh city from only five different speed ranges (0, 0–24, 24–32, 30–40 and 40–48 km/h) [14].

Methodology of Hanoi Motorcycle Driving Cycle (HMDC) Construction

Driving Data Collection Method

There are two ways to collect driving data, including on-board driving and emission measurement method and car chasing method. The first requires on-board emission measuring devices which currently are not available in Vietnam and too expensive for a small scale research project. The second was thus chosen for collecting driving data. For this car chasing method, a time-speed measuring device was installed on the testing motorcycles to chase the traffic flow.

Procedure of HMDC Development

Figure 2 illustrates the procedure for the development of HMDC, which comprises the following 5 steps:

- Selecting target experimental streets by local traffic management experts
- Selecting target test motorcycles
- Designing and fabricating time-speed measuring device
- Organizing experiments to acquire on-road time-speed data which encompass representative driving behaviors as much as possible
- Performing on-road time-speed data analysis to form HMDC driving cycle.

The HMDC driving cycle was developed based on time-speed data analysis. 10assessment parameters were employed in the analysis as comparative criteria of driving cycles: Average speed of the entire driving cycle, v_1 (km/h); average running speed, v_2 (km/h); average acceleration of all acceleration phases, a (m/s^2); average deceleration of all deceleration phases, d (m/s^2); mean length of driving periods, c (s); time proportions of idling modes, p_i (%); time proportions of acceleration modes, p_a (%); time proportions of cruising modes, p_c (%); time proportions of deceleration modes, p_d (%); and root mean square acceleration, RMS (m/s^2).

The definition of driving modes is as that of Kuhler and Kastens (1978) [12] and Tsai, et al. (2005) [10], including: Idling mode, zero speed; acceleration mode, the positive incremental speed changes of more than 0.1m/s^2; cruising mode, the absolute incremental speed changes of less than or equal $0.1m/s^2$; and deceleration mode, the negative incremental speed changes of less than $-0.1m/s^2$.

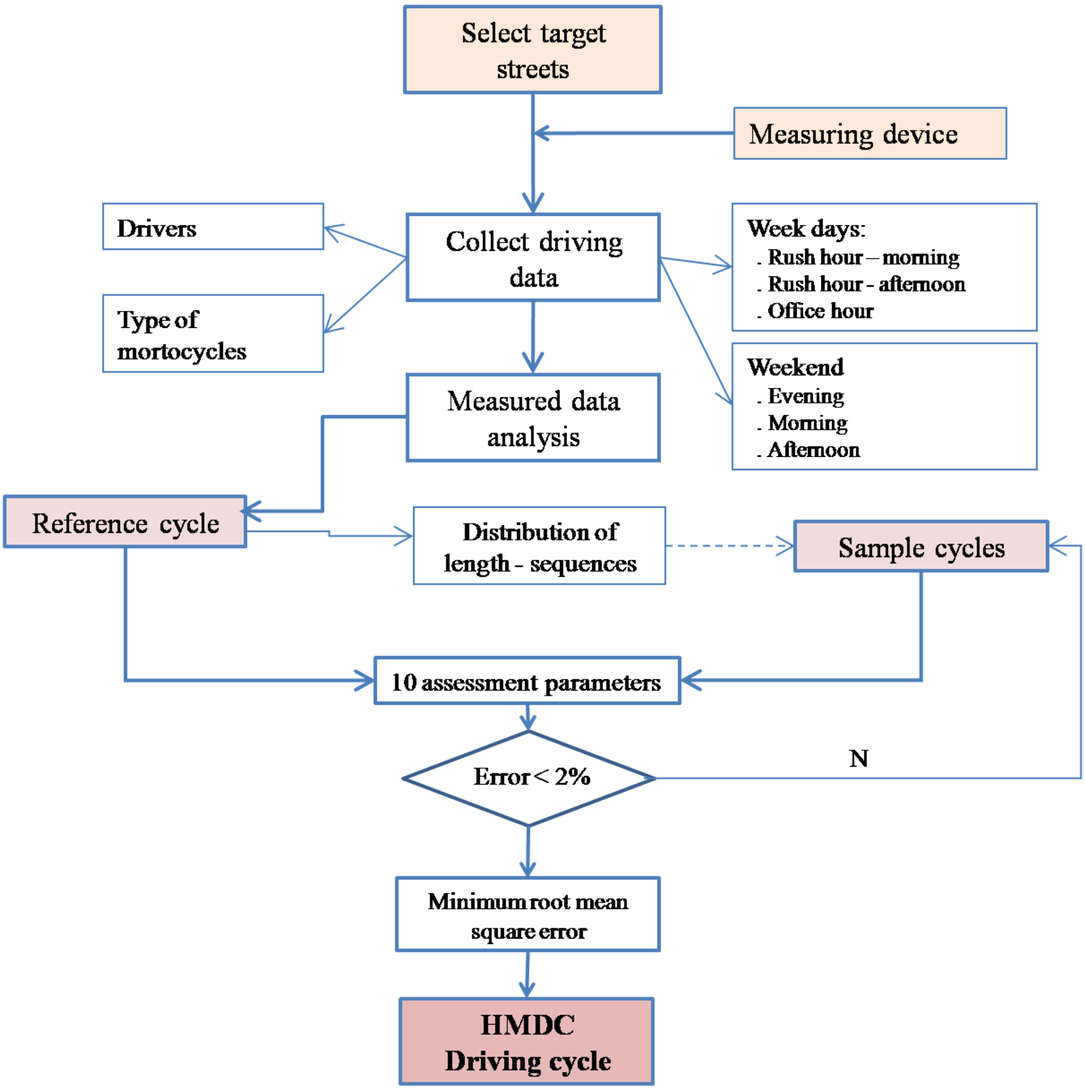

Figure 2. Flow chart of HMDC development

On-road time-speed data, called a reference cycle, consists of many driving trips. Of each driving trip, there are many driving periods, separated by idle stage (e.g. stop) due to either traffic jam or traffic light. The time duration of each period is called the length of that period. From the reference cycle, the average duration of a stop and the average duration of a driving period are calculated. Then the number of desired driving periods and stops can be calculated from the desired cycle time, usually from 5 to 60 minutes [15].

A length-sequences distribution of all driving periods is created, from which the most representative length intervals for forming sample cycles are determined based on number of desired driving periods calculated. A sample cycle is formed randomly by combining driving periods drawn from each representative length interval, and must have the closest statistics of the 10 assessment parameters (the absolute relative error equal or less than 2%) compared with those of the reference cycle.

In case of no sample cycle is obtained with the absolute relative error equal or less than 2% as illustrated in Figure 2, the error is raised to 5% with the attention to the limited number of sample cycles created. The sample cycle which has minimum root mean square error is chosen as HMDC driving cycle.

Experimental

Selection of Representative Streets and Motorcycles for Road Test

Representative streets were selected under the advice of a traffic management expert from the Vietnam Transport Development Strategy Institute. The selection was aimed at current driving conditions while a long term application of the driving cycle was also considered. The following criteria were used:

Area: Based on Hanoi area prior to the expansion of Hanoi metropolitan area by the end of 2008, the Haidep master plan [16] has characterized the transportation area of Hanoi into 4 areas, including old quarter, old street areas, old inner city areas, new areas and suburbs

Limited speed: The maximum speed of motorcycles is generally restricted to 40 km/h, except in the streets in the new areas and suburbs where it is limited to 50 km/h

Traffic flow: Both one-way and two-way streets are taken into account

Traffic congestion: In order to obtain the real traffic pattern, both congested and uncongested streets were selected

Streets with physical dividers: In Hanoi the streets are usually narrow; however for the purpose of reducing chaotic conditions of the traffic, physical dividers are installed on some streets.

Streets with reserved lanes for motorcycles: Due to narrow streets and poor traffic infrastructure, almost all streets in Hanoi do not have lanes reserved for motorcycles; and, thus only one street with reserved lane for motorcycles was selected.

Base on the above criteria, ten representative streets for conducting on-road measurements were selected, and their description is given in Table 2.

Table 2. Selected Streets and Their Descriptions

No.	Streets	Features														
		Length (Km)	Old quarters	Old street areas	Old inner city	New areas and suburbs	40 km/h limited	50 km/h limited	One way	Two ways	Congestion	Free	With physical dividers	Without physical dividers	With reserved lanes for MCs	No reserved lanes for MCs
1	Hang Da - H.dieu - H.Ga - H.Cot	0.878	✓				✓			✓				✓		✓
2	H.Giay-H.Duong-H.Ngang-H.Dao	0.752	✓				✓		✓					✓		✓
3	Pho Hue - Hang Bai	1.882		✓			✓		✓					✓		✓
4	Tran Hung Đao	2.144		✓			✓			✓				✓		✓
5	Kim Ma	2.370			✓		✓			✓	✓		✓		✓	
6	Nguyen Thai Hoc	1.650			✓		✓		✓			✓		✓		✓
7	Tay Son - N.L.Bang – T.D.Thang	3.745			✓		✓			✓	✓		✓			✓
8	Pham Hung	4.014				✓		✓		✓		✓	✓			✓
9	Truong Chinh	2.257				✓	✓			✓	✓		✓			✓
10	Giai Phong	4.700				✓		✓		✓	✓		✓			✓

The experiments were conducted on selected streets from May to December 2008, i.e., the driving behaviors were obtained for sunny, cloudy and rainy days. The targeted driving behaviors consist of traffic behaviors at rush hour in the morning, 7:30 - 8:30 AM; during office hours, 9:00 - 11:00 AM; and at rush hour in the afternoon, 5:00 - 6:00 PM; and in the weekends, 9:00 - 11:00 AM, 4:00 - 5:00 PM, 8:00 - 9:30 PM. For driver behavior, a group of 10 people conducted the on-road measurements with either a driver or a driver with a passenger sitting behind.

The motorcycle fleet in Hanoi consists mainly of 4-stroke small capacity (less than 150cc) motorcycles produced by Honda, Yamaha and VMEP. The market share of each company and other information regarding motorcycle types, ages and etc., are scant and uncertain. With the advice of local experts, Honda Wave RS, 110cc, Honda Super Dream, 100cc, Yamaha Jupiter MX, 110cc and VMEP SYM Attila, 125cc motorcycles were selected to be the on-road test motorcycles. These test motorcycles were private and in-used individuals thus before the on-road tests, they were maintained to their best conditions to ensure the stable driving behavior during the tests.

Time-Speed Measuring Device

To acquire the on-road data, a time-speed measuring device was designed and manufactured. It consists of two sensors; one is for wheel's speed measurement and the other for wheel's radius measurement. The motorcycle speed, v, in [m/s] is calculated by the following equation:

$$v = R.\pi.n/30 \tag{1}$$

Where n is the revolution of the wheel in [rpm] measured continuously by the wheel's speed sensor, and R is the wheel radius in [m] measured by distance sensor once before each on-road test.

Both sensors were mounted on the front wheel of the test motorcycle. A frequency-voltage transducer and data acquisition system acquired the time-speed data during the testing. Rotational speed was obtained via a gear with 6 teeth located at 60º intervals. This gear was mounted next to the front wheel central hub while the speed sensor was located on a fixed L-shaped metal bracket attached to the left tube of the motorcycle's front fork. In addition, the gear shift signal was obtained directly from the indicator of the testing motorcycles.

The system recorded data every second and stored in a laptop for later analysis. Figure 3 shows the time-speed measuring device installed on the front wheel. The accuracy and reliability of the time-speed measuring device were assessed and certified by Measuring Center of Vietnamese Directorate for Standards, Metrology and Quality.

Figure 3. Speed and tire radius sensors

Dynamometer Testing

Five motorcycles were chosen for dynamometer testing, of those 4 were in-used motorcycles with the age between 2 and 9 years old, and a brand-new one. Specifications of testing motorcycles are given in Table 3.

Table 3. Motorcycle Specifications Used in Dynamometer Testing

No.	Names	Capacity (ml)	Makers	Weight (kg)	Ages, respect to year 2009 (year)	Transmission	Mileage (km)
1	Jupiter MX 110	110	Yamaha	97	4	manual	22 020
2	Wave RS 100	100	Honda	100	3	manual	26 400
3	Attila Victoria 125	125	SYM	107	2	automatic	10 167
4	Super Dream 100	100	Honda	95	9	manual	44 000
5	Wave RSX 100	100	Honda	100	0	manual	1 000

For safety and reliability of the results, the test motorcycles were first examined by a mechanic of a Honda motorcycle dealership, and the fuel tank was then filled up before testing. The next day, prior to the dynamometer testing (on AVL Zollner CD20 inch) the test motorcycles were warmed up. The warm-up consisted of a cruise for an equivalent distance of 10 km at 50 km/h, followed by an idle stage for 40 s. The test bench seting comprised the inertia mass of 169.5 kg, and the road load resistance coefficients: F0 = 40.4 N, F1 = 0.473 N/km/h and F2 = 0.0294 N/km/h^2 obtained from on-road test data and road load simulation parameters [4].

RON92 gasoline was used for all motorcycles during the tests. This fuel was tested and complied with Vietnam standard for unleaded gasoline fuel - TCVN 6776-2005 (equivalent to Euro 2 reference gasoline fuel) [4].

Exhaust Emission Sampling and Analysis

Exhaust gas was diluted following constant volume sampling concept (CVS), and the exhaust gas samples were continuously collected for the entire driving cycles of ECE R40 and HMDC. CO, THC, NO_x and CO_2 analyzers located in AVL emission test bench, are controlled by CESAR software to sample the diluted exhaust and analyzed both instantaneously and from the bags. The background pollutant concentrations were also measured routinely and deducted from the test results.

Results and Discussions

HMDC Driving Cycle

Of a total of 343 on-road driving trips, 6 were conducted in rainy condition; 174 during working days and 169 in the weekends.The reference cycle thus consisted of 343 driving trips, including stops and 905 driving periods. These driving periods were then used to make length-sequences distribution (see Figure 4). The 10 assessment parameters were also calculated for the reference cycle and for all driving periods.

The average duration of a driving period of the reference cycle was 138.35 s. With the desired length of the HMDC cycle close to that of ECE R40 cycle (1170 s), the number of desired driving periods was calculated and rounded off as 8, i.e., eight representative length intervals from the length-sequences distribution were selected for forming the sample cycles. In Figure 4, these representative length intervals are illustrated by the level-off columns.

Through randomly combining periods drawn from representative length intervals (one period from each interval), 14 sample cycles were created. Relative errors in percent of assessment parameters of sample cycles with those of reference cycle are shown in Table 4, from which the cycle with minimum root mean square error (0.5% for cycle No.3) was selected as the HMDC driving cycle.

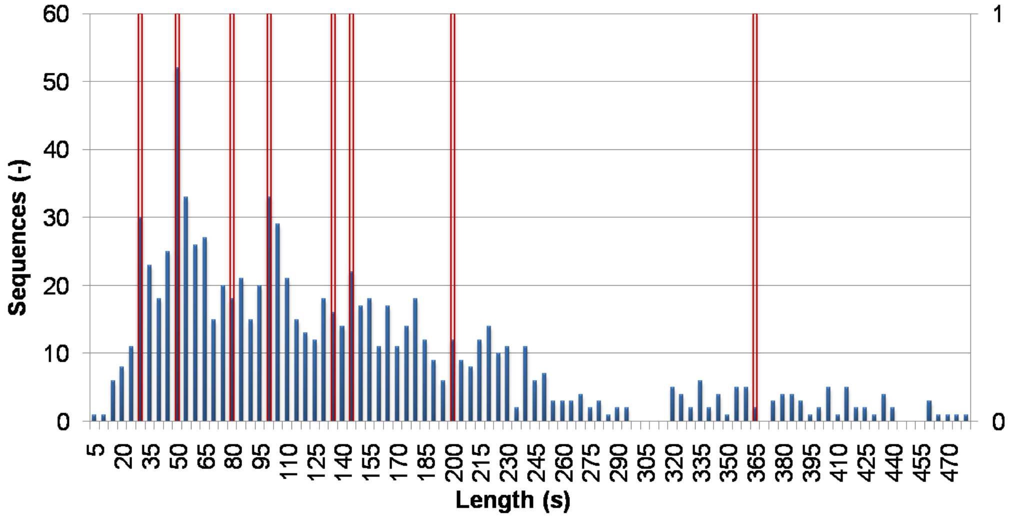

Figure 4. Distribution of length-sequences

Table 4. Relative Errors (in percent) of the Assessment Parameters of the Sample Cycles Compared with Those of the Reference Cycle

Cycles	v_2 (%)	a (%)	d (%)	c (%)	p_a (%)	p_d (%)	p_c (%)	RMS (%)	RMSE (%)
No. 1	-0.369	0.458	1.131	-1.075	-0.007	-0.484	0.901	-0.071	0.692
No. 2	-0.442	-0.643	0.221	-1.168	-0.179	0.126	0.072	-0.218	0.515
No. 3	-0.498	-0.320	0.146	-1.168	-0.390	0.392	-0.010	0.047	0.505
No. 4	-1.078	1.012	-0.377	-1.168	-0.842	0.872	-0.010	-0.031	0.803
No. 5	-0.848	-0.343	-0.013	-1.168	-0.163	0.249	0.112	-0.305	0.547
No. 6	-0.376	0.185	-0.053	-1.168	-0.635	0.435	0.432	0.856	0.618
No. 7	-1.028	0.898	0.414	-1.168	-0.540	0.872	-0.659	0.042	0.781
No. 8	-1.095	0.540	-0.772	-1.168	-1.119	0.894	0.853	-1.145	0.971
No. 9	0.253	-0.734	0.370	-1.168	-0.020	0.296	-0.290	-0.232	0.540
No. 10	0.973	0.258	0.962	-1.075	-0.630	0.626	0.358	-0.110	0.709
No. 11	-0.220	1.013	-0.834	-1.168	0.303	0.083	-0.896	0.215	0.714
No. 12	-0.986	0.200	-1.081	-1.075	0.380	-0.127	-0.643	0.349	0.710
No. 13	0.918	0.901	-0.355	-1.168	-0.934	0.706	0.523	0.896	0.836
No. 14	0.149	-0.413	-1.167	-1.168	-0.233	0.226	-0.012	-0.887	0.690

This HMDC cycle depicted in Figure 5 has 8 driving periods of 1 250 s in length and 7 076 m total distance with a maximum speed and an average speed of 39.4 and 20.40 km/h, respectively.

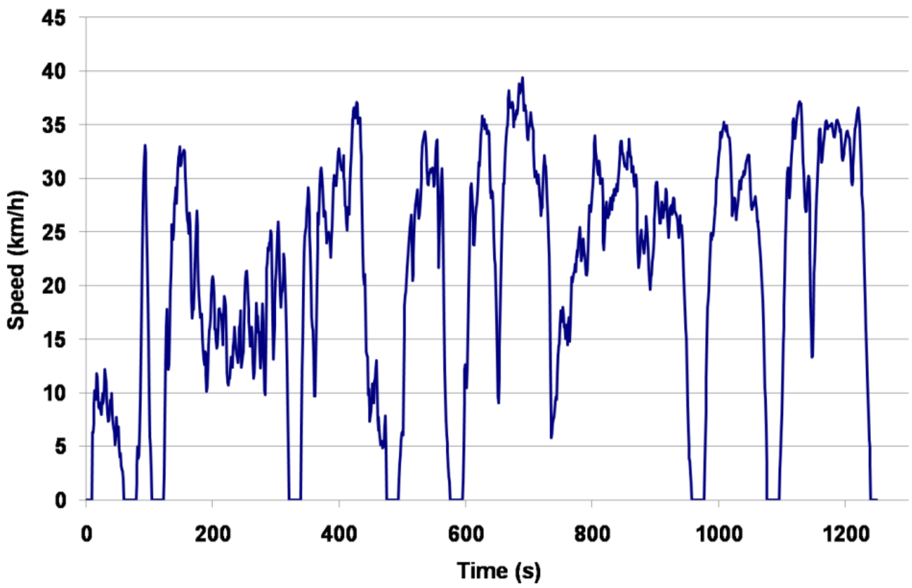

Figure 5. HMDC driving cycle

Comparison Between HMDC and Other Driving Cycles

In Table 5, the assessment parameters of the HMDC driving cycle are compared with those of other driving cycles such as European (ECE), American (US 75), Japanese (10-15 mode), Hong Kong (KH cycle), Taiwan (TWDC), Kaohsiung (KHM) and the Worldwide-harmonized Motorcycle Test Cycle (WMTC) [17]. The mean length of driving period, c, of 136.6 s is much higher than those of other driving cycles, indicating shorter duration of the red light of the traffic signals and lesser traffic jams in Hanoi. The average speed over the whole cycle, v_1, of 20.4 km/h is comparable to that of 10-15 mode and KHM cycles; however the average running speed, v_2, is not as high (only 23.1 km/h), possibly due to low proportion of idle modes (only 13.2 %). In addition, the low idling time is believed to be a result of short stop intervals of the traffic signals (usually less than 45 s). The values of v_1 and v_2 of the HMDC driving cycle are closer to those of the TWDC cycle.

The mean acceleration, a, and deceleration, d are lower than those of other driving cycles which can be attributed to the high density of the traffic, which makes it impossible for the motorcycle to quickly accelerate. On the other hand, the combination of high traffic density and low running speed does not require abrupt deceleration of the motorcycle. Furthermore, the proportion of cruising time of 18.2 %, is much lower than that of the ECE cycle (32.3 %) but comparable to that of TWDC and WMTC-Part1 cycles, which indicates a high frequency of speed variations of motorcycle driving characteristics in Hanoi. On the other hand, this cruising proportion is higher than that of KH (9.4%) and KHM (8.7%) cycles, indicating a shorter idling time in Hanoi as compared to Hong Kong and Kaohsiung city. Finally, the proportion of the acceleration, p_a, and deceleration, p_d, modes are higher than those of other cycles. This shows once again the high fluctuations of the speed in actual traffic conditions in Hanoi.

Table 5. Comparison of Assessment Parameters of Different Driving Cycles

Driving cycles	Assessment parameters										References
	v_1(km/h)	v_2(km/h)	a(m/s^2)	d(m/s^2)	c(s)	p_i(%)	p_a(%)	p_c(%)	p_d(%)	RMS(m/s^2)	
ECE	18.7	27.1	0.75	0.75	45.0	30.8	18.5	32.3	18.5	0.770	Tong et al., 1999
US75	34.1	41.6	0.61	0.71	70.0	18.0	33.1	20.4	28.5	0.753	Tong et al., 1999
10-15 mode	22.7	32.7	0.55	0.66	64.3	31.4	25.9	21.2	21.5	0.596	Tong et al., 1999
KH cycle	15.4	22.2	0.55	0.59	49.6	31.4	30.6	9.4	28.6	0.670	Tong et al., 1999
TWDC	19.4	23.8	0.80	0.93	77.3	19.5	31.5	18.7	30.3	-	Tsai et al., 2005
KHM	21.0	29.0	0.58	0.61	111.3	27.7	32.6	8.7	31.0	0.590	Tsai et al., 2005
WMTC-Part1	24.4	29.4	0.66	0.65	61.1	19.8	29.8	21.2	30.5	0.652	ECE/Trans/WP.29/2005/55
HMDC	**20.4**	**23.1**	**0.40**	**0.44**	**136.6**	**13.2**	**36.4**	**18.2**	**32.2**	**0.431**	**This study**

Exhaust Emission Factors and Fuel Consumption of HMDC and ECE Cycles

The exhaust emission factors for selected motorcycles (with specifications given in Table 3) were obtained using a chassis dynamometer located at the Laboratory of Internal Combustion Engines, Hanoi University of Science and Technology, by implementing the developed HMDC and the European ECE R40 driving cycles. Though the WMTC cycle can be used for emission factors and fuel consumption comparative measurements, the ECE R40 is given priority as ECE cycles are regulated in Vietnam emission type approval tests for new vehicles. Furthermore the WMTC cycle shows quite far difference in mean speed, acceleration and deceleration compared to those of practical traffic condition in Hanoi where the main on-road transport means are motorcycles.

Exhaust emission factors, fuel consumption for the test motorcycles obtained from HMDC and ECE R40 driving cycles together with the combined average of the emission factors of the two driving cycles are shown in Table 6.

Table 6. Averaged Emission Factors and Fuel Consumption Obtained from Motorcycles Tested on Chassis Dynamometer Using HMDC and ECE Driving Cycles

Emission Factors	HMDC	ECE R40	HMDC/ECE
THC (g/km)	**1.017**±0.300	**1.186**±0.225	0.858
NO_x (g/km)	**0.180**±0.079	**0.108**±0.029	1.668
CO (g/km)	**12.592**±2.565	**12.906**±2.447	0.976
CO_2 (g/km)	**32.478**±6.865	**31.321**±5.454	1.037
Fuel Consumption (*l*/100km)	**2.360**±0.277	**2.345**±0.178	1.006

The THC, CO, CO_2 emission factors and fuel consumption during HMDC and ECE cycles are quite similar. However the NO_x emission factor during HMDC is 66.7% higher than that of ECE. As seen in Table 5, while there is a high fluctuation of motorcycle's speed of the HMDC cycle compared to ECE cycle, the average acceleration (a) and the average deceleration (d) of HMDC cycle are much lower than those of ECE cycle, resulting in more complete combustion, and consequently lower THC and CO emissions in the HMDC cycle. On the other hand more complete combustion would produce higher combustion temperature, resulting in higher NOx emission for the HMDC cycle.

As seen in Table 1, the differences between emission factors obtained from the KHM and ECE cycles are much less with in-used motorcycles (with high emission level) than with new motorcycles (with lower emission levels). It is imperative to emphasize that almost all test motorcycles emit high level of emissions (Euro 2 emission standard has been only applied in Vietnam since July 1, 2007). Thus, the emission levels of THC and CO of test motorcycles are high, causing the differences between emission factors obtained from any driving cycle to be minor. However, it is anticipated that with more stringent emission standards for new motorcycles these differences will be much higher. As a result there is a need in developing a real world driving cycle for accurate emission factors determination.

Figure 6 shows emission factors obtained from HMDC and ECE R40 cycles in comparison with limits of the Euro2 emission standard for motorcycles. As seen in the figure, while the emission factors of THC and NO_x meet Euro2 limits, the emission factor for CO exceeds more than twice the limit. This substantiates the findings from previous research that motorcycles contribute a very high proportion of CO emission in Vietnam.

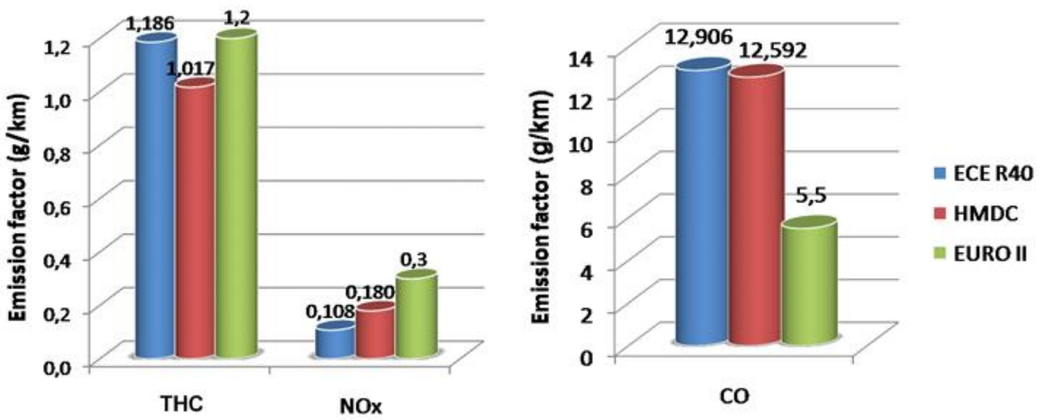

Figure 6. Comparison of exhaust emission factors obtained from HMDC and ECE driving cycles and Euro2 limits

Conclusions

The HMDC driving cycle for motorcycles developed out of 343 driving trips can be used to represent the actual driving conditions in Hanoi since it takes into account a number of contributing factors such as road conditions, motorcycle types, driver's behavior, time (rush and non-rush hour, week days and weekend) and weather.

The developed HMDC driving cycle consists of 1 250 s in length and 7 076 m in distance with a maximum speed and an average speed of 39.4 and 20.4 km/h, respectively. These assessing parameters are quite similar to those of other real world driving cycles such as US 75, KH, TWDC, KHM and WMTC-Part1 cycles; however they are very much different with those of polygonal driving cycles such as ECE and 10-15 mode.

Emission factors obtained from HMDC are comparable with those from ECE R40 in CO, CO_2, THC emissions and fuel consumption but not NO_x emission factor, which is 66.7% higher. The high emission levels of motorcycle fleet in Hanoi has contributed in small differences in THC and CO emissions when the motorcycles are tested with HMDC and ECE cycles, however these behaviors are believed to be changed as higher emission standards are applied. The NO_x emission obtained from HMDC and ECE cycles are very different which shows the necessity of developing a real world driving cycle for motorcycles for accurate emission factors development.

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