Real-World Driving Cycle for Motorcycles: A Comparative Study Between Delhi and Edinburgh

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Abstract: Driving cycle is an essential requirement to evaluate the exhaust emissions of various types of vehicles on the chassis dynamometer test. This study presents a real-world comparison of the driving cycles of Edinburgh motorcycles in two world cities: Edinburgh in Scotland and Delhi in India. The two driving cycles (Edinburgh Motorcycle Driving Cycle [EMDC] and Delhi Motorcycle Driving Cycle [DMDC]) were developed through the analysis of experimental data. These data were collected from trips on a number of routes in each city. In Edinburgh, five different routes between the home addresses in the surrounding areas and place of work at Edinburgh Napier University were selected. In Delhi, data were collected from East Delhi (Geeta Colony) to Central Delhi (Raisina Road). The data collected were divided into two categories of urban and rural roads in the case of Edinburgh, whereas it was only the urban route in Delhi. Forty-four trips were made on the five designated routes in both urban and rural areas, and 12 trips were made in Delhi. The aims of the study were to assess the various parameters (i.e. motorcycle speed, cruise, accelerations and decelerations, and percentage time spent in idling) and their statistical validity over total trip lengths for producing a real-world EMDC in each of the two cities. The results show that EMDC has a cycle length of 770 and 656 s for urban and rural trips, respectively, which was found higher than Europe driving cycle length. Time spent in acceleration and deceleration modes was found to be significantly higher than any other driving cycle reported to date for motorcycles, reflecting a typical characteristic of the driving cycle in Edinburgh; this was presumably due to diverse driving conditions of motorcycles in the city. On the other hand, in Delhi, the DMDC has a cycle length of 847.5 s for the urban trips, which was higher than EMDC length. The overall percentage time spent in acceleration in Delhi was higher than that in Edinburgh, whereas the time spent in deceleration was lower in Delhi than that in Edinburgh. The overall average speed in Delhi was slightly higher than that in Edinburgh.

Keywords: Motorcycle Driving Cycle, Edinburgh, Delhi, Global Positioning System (GPS), Vehicle Operating Modes

1 Introduction

A driving cycle for a vehicle is a representation of a speed–time sequenced profile developed for a specific area or city. It has been widely used in a large number of transport-related pollutant emissions for the accurate estimation of air pollutant emissions and databases for building emission inventories. Over the past few decades, several studies have been carried out to determine the driving cycles for private cars and light goods vehicle as part of enhancing traffic management systems, determining fuel consumption patterns and reducing transport impacts on health (Hung et al., 2007; Lee et al., 2005; Saleh et al., 1998; Saleh, 2007; Tzirakis et al., 2006). However, studies reporting the driving cycle for motorcycles under typical driving conditions are still rare in Europe. Motorcycles have a marginal share (3% of motor vehicles) in the UK traffic fleet; however, their ownership is consistently increasing. Motorcycle's traffic has increased by 37% from 1996 to 2006 in the United Kingdom and travelled around 5.2 billion vehicle-km in 2006 with fleet of average age of 8.5 years (Compendium of Motorcycling Statistics, 2007). In Edinburgh, motorcycle ownership has almost doubled in the last 10 years.

An accurate quantification of emissions is important for proper emission control and technological development of clean and environmental friendly motorcycles. This not only helps to reduce global warming and carbon dioxide emissions but also helps to meet the targets for reducing green house gases (about 60% reduction by 2050 from 1990 levels in United Kingdom).

Therefore, many databases have been created worldwide for motorcycle emissions. The European Commission Directives (97/24/EC, 2002/51/EC) established common standards and procedures for evaluating motorcycle's emissions in Europe as pre–Euro (up to 1999), Euro 1 (from 1999), Euro 2 (from 2003) and Euro 3 (2006). Euro 3 standards for mopeds (fitted with engines smaller than 50 cc) were also implemented from 2007. COPERT 3 and COPERT 4 (Computer programme to calculate emissions from road transport) models are widely used to calculate both regulated and unregulated emissions of motorcycles. However, their emissions are based on fixed legislative driving standards but not on the local driving conditions (Gkatzoflias et al., 2007; Ntziachristos and Samaras, 2000).

This paper presents an investigation of a real-world driving cycle for motorcycles in Edinburgh and Delhi. The driving cycle represents trips performed from the city centre of Edinburgh or place of work to the residential addresses within and outside the city centre. Data were collected by installing the equipment in motorcycles and by carrying out an emission survey questionnaire. The trips, classified into urban or rural, were made along the east–west and north–south side encompassing the entire city centre of Edinburgh, whereas only urban trips were considered in the case of Delhi. Finally, each of the Edinburgh Motorcycle Driving Cycle (EMDC) and the Delhi Motorcycle Driving Cycle (DMDC) were produced by assessment of its parametric values. Comparisons of the results were made with a number of driving cycles including those of the World Motorcycle Test Cycle (WMTC), some driving cycles in Taiwan, Edinburgh driving cycle and Economic Commission for Europe driving cycle.

2 Experimental Methodology

Data for driving behaviour can be collected using various methods for collecting data to develop a driving cycle. These include data collection directly from target vehicles by installation of a data acquisition system in the target vehicles. However, instructions given to drivers may affect the normal driving behaviour. The chase car techniques, on the other hand, have minimal effect on driver behaviour and result into more realistic driving data. Techniques such as chase car, field survey questionnaires and instrumentation of motorcycles are frequently used to collect the speed–time sequence (Chen et al., 2003; Shafiepour and Kamalan, 2005). Micro-simulation methods based on psychophysical car following models have also been used for data collection of driving behaviour. These methods can also reproduce traffic flow very realistically under different real-world driving conditions (Fellendorf and Vortisch, 2001; Kumar et al., 2007). However, these techniques are expensive and difficult to operate in the field. In this study, data acquisition system has been installed in the target vehicle which is driven by the vehicle owner for general commuting purposes, as well as chase car technique (Booth et al., 2002) has been employed to collect data for the EMDC study. The equipment and methodology used to collect the data are discussed in the subsequent sub-section.

There were five rural and four urban routes as shown in Table 1. Each testing period comprised a series of major kinematics sequences (i.e. speed vs. time curve) which were intercepted by number of minor kinematics sequences (also called micro-trips). Each driver used the defined routes during weekdays. Forty-four urban and rural trips were composed of sub-micro trips caused by several stops at traffic signals or due to congestion. The Performance Box (PB) tracked these minor kinematic sequences for all the trips over different routes. Finally, EMDCs were derived by examining the statistical resemblance of 12 parameters as shown in Table 1. Part of these assessment parameters was also used in assessment of deriving driving cycle by several researchers (Andre, 2004).

Table 1 Value of the assessment parameters for different test run on five routes

Route	Route Types	D ($m\ s^{-2}$)	A ($m\ s^{-2}$)	V1 ($m\ s^{-2}$)	V2 ($m\ s^{-2}$)	C (s)	Pi (%)	Pa (%)	Pd (%)	Pc (%)	M	Root mean square (RMS)	Positive acceleration kinetic energy per unit distance (PKE)	Length(m)
001	Urban	0.89	0.97	39.32	41.18	710.33	0.32	42.98	48.32	8.44	1413	1.74	1.15	7783.51
	Rural	0.94	0.93	70.4	72.3	1179.64	0.14	43.07	47.45	9.38	1827	3.03	4.05	23233.49
002	Urban	0.98	1	32	34.5	622.68	1.35	44.01	47.95	6.94	1144	0.94	8.53	5375.41
	Rural	0.98	0.73	84.27	86.49	1210.76	0.69	44.02	44.13	11.53	2122	5.05	3.57	23718.08
003	Urban	1.27	1.12	38.85	40.98	488.82	2.33	44.99	47.14	5.63	1116	2.98	1.46	5611.49
	Rural	0.95	0.89	49.73	53.17	656.37	0.77	44.7	46.32	8.28	1349	2.09	2.05	9015.19
004	Urban	2.59	1.28	33.5	38.85	769.63	1.51	44.45	46.87	7.24	1251	7.83	2.81	7313.59
005	Urban	1.18	1.1	31.35	35.03	536.56	1.32	43.43	47.35	7.98	1028	3.71	0.69	3850.44
	Rural	0.81	0.76	70.17	73.06	1432.33	0.63	44.47	41.9	13.03	2732	3.02	3.51	28523.7
Average	Urban	1.382	1.094	35.004	38.108	625.604	1.366	43.972	47.526	7.246	1190	3.44	2.928	6.51
	Rural	0.736	0.662	54.914	57.004	895.82	0.446	35.252	35.96	8.444	1606	2.638	2.636	18.655
Standard deviation	Urban	0.69	0.12	3.81	3.19	116.8	0.72	0.8	0.6	1.08	148	2.68	3.23	1586.44
	Rural	0.07	0.1	14.23	13.71	328.79	0.28	0.72	2.46	2.13	578	1.25	0.86	8417.4
Coefficient of variation (%)	Urban	0.5	0.11	0.11	0.08	0.19	0.52	0.02	0.01	0.15	0	0.94	0	0.24
	Rural	0.08	0.12	0.21	0.19	0.29	0.51	0.02	0.05	0.2	0	0.37	0	0.45

Note: Average values are drawn across all the 44 test runs for urban and rural sections.

The mean value, standard deviation and coefficient of variations (COVs) of those assessment parameters were estimated for each of the 44 trips as in Table 2 for the five test sections. The COV values were calculated to show the variations in the performance of the test runs in each of the urban and rural contexts. A further refining of the driving cycle was carried out by calculating the absolute sums of the relative error (S_j) and then by selecting the driving cycle with minimum value of S_j. The relative error value for each of the parameters (Δ_k) is as follows:

$$\Delta_k = \frac{(\bar{P} - P_{ijn}) * 100}{\bar{P}},$$

where k is an assessment parameter (k varies from 1 to 12), Δ_k is the value of the relative error for parameter k, $\bar{P}$ is overall mean value of parameters, and P_{ijn} is a parameter with a value of a route i (between 1 and 5), route category j (1 for urban and 2 for rural category) and n (the number of test runs for each motorcycle). The absolute sum of the relative errors (S_j) was calculated for each (urban and rural) route type by summing up the individual relative error for a given route:

$$S_j = \sum_{k=1}^{12} \Delta_k .$$

The driving cycle associated with minimum value of S_j has been selected as a representative of EMDC. The results are discussed in following section. The minimum value of the absolute relative error was observed at test run 003 and 004 for urban and rural sections and was selected to represent the EMDC for each of the urban and rural sections, respectively.

The mean values of the key parameters are shown in Table 1, with the derived EMDC for urban and rural sections shown in Figures 1 and 2. Speed is the most important criteria of traffic quality and as an important factor influencing the emissions of the vehicle. The average speeds of motorcycle in the urban and rural are 33.5 and 49.73 km h^{-1}, but in some cases, drivers exceeded the speed limits. For example, the maximum average speeds for the urban and rural EMDC were 70 and 120 km h^{-1}, respectively. Similarly, differences in the cycle length, speed and vehicle operating time were observed. The average trip lengths for the urban and rural EMDC are 7.3 and 9.1 km.

The rate of average deceleration–acceleration for urban EMDC was found to be higher than average deceleration–acceleration rate for rural EMDC and was probably caused by the larger number of signals on urban roads. For urban EMDC, average running speed without idling (V2) and average speed of entire driving cycle (V1) were 38.85 and 33.55 km h^{-1}, respectively. The values for urban EMDC were lower than those for rural EMDC. These differences were attributed to the higher speed limit (112 km h^{-1}) adopted by highway agency in United Kingdom for rural sections compared with urban ones (48 km h^{-1}). The mode of vehicle can be divided into idling accelerating, decelerating and constant speed. For urban sections, percentage time spent in various operating modes such as idling (Pi), acceleration (Pa) and decelerations (Pd) is higher for urban sections than rural. Furthermore, time spent in cruise (Pc) was lower for urban than for rural sections for the probable reasons discussed above.

Overall mean length of trips for the five test runs was 18.65 and 6.51 km for rural and urban travel, respectively, but trip time on rural roads was approximately 60% of the journey time compared with only 40% on urban roads, again seemingly due to the small number of traffic signals on the rural roads.

3 Motorcycle Driving Cycle of Delhi

During the course of the current research investigation of Delhi, motorcycle driving cycle was carried out in Delhi (Kumar et al., 2008; Saleh et al., 2009). Rapid increase of motorcycle ownership in Delhi has resulted in high pollution in road traffic as well as congestion in cities. The vehicle population in Delhi is highest among all the metropolitan cities (Bombay, Calcutta, Delhi and Madras) in India. During 1985-2001, the

Table 2 The sums of absolute relative errors of the assessment parameters for urban and rural routes

Route	D ($m\ s^{-2}$)	A ($m\ s^{-2}$)	V1 ($km\ h^{-1}$)	V2 ($km\ h^{-1}$)	C (s)	Pi (%)	Pa (%)	Pd (%)	Pc (%)	M	Root mean square (RMS)	Positive acceleration kinetic energy per unit distance (PKE)	Sum of absolute error (%)
Rural routes													
R003	0.14	0.16	0.06	0.04	0.22	0.26	0.13	0.14	0.01	0.00	0.16	0.17	**1.61**
R005	0.06	0.08	0.13	0.13	0.23	0.18	0.13	0.09	0.22	0.00	0.08	0.15	1.72
R002	0.15	0.06	0.21	0.21	0.16	0.22	0.12	0.11	0.16	0.00	0.29	0.16	2.01
R001	0.13	0.18	0.13	0.13	0.15	1.34	0.11	0.15	0.06	0.00	0.08	0.21	2.74
Urban routes													
U004	0.29	0.09	0.03	0.01	0.11	0.06	0.01	0.01	0.00	0.00	0.34	0.03	**1.00**
U003	0.05	0.01	0.06	0.04	0.17	0.25	0.01	0.01	0.18	0.00	0.09	0.62	1.54
U002	0.25	0.06	0.06	0.06	0.00	0.01	0.00	0.01	0.03	0.00	1.63	0.40	2.53
U005	0.10	0.00	0.07	0.05	0.10	0.02	0.01	0.00	0.06	0.00	0.04	1.98	2.55
U001	0.34	0.08	0.07	0.05	0.07	2.00	0.01	0.01	0.09	0.00	0.60	0.95	4.35

Note: For both urban and rural routes, the error was also normalised by dividing with observed minimum value of sum of absolute error.

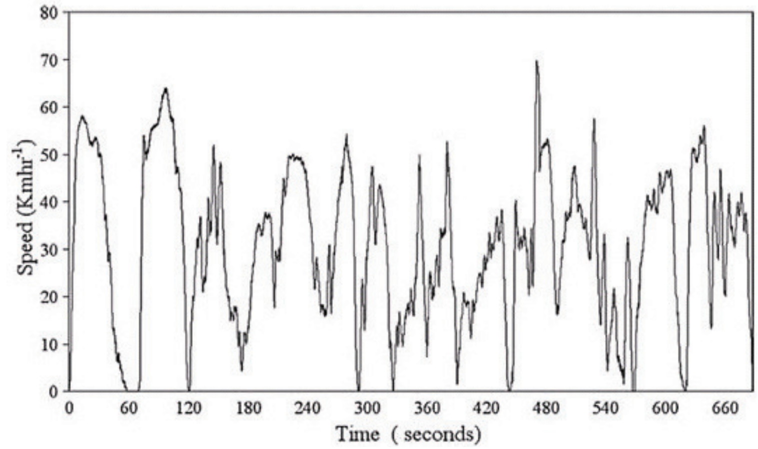

Figure 1 - Driving cycle EMDC (urban)

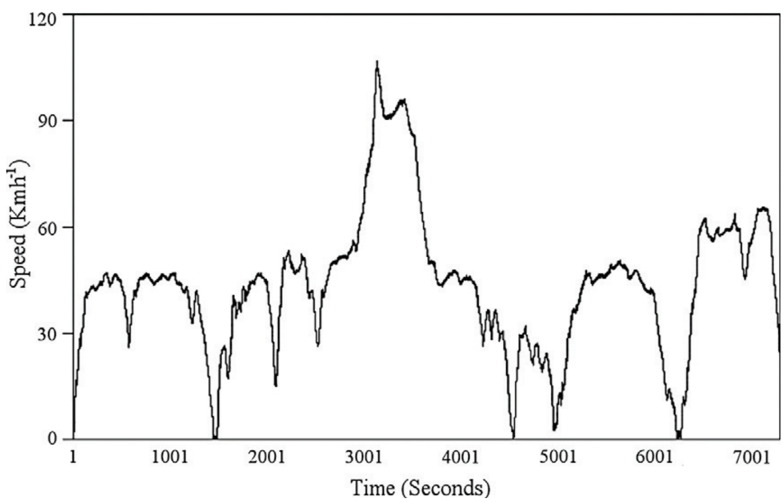

Figure 2 - Driving cycle EMDC (rural)

total number has multiplied four times (see URTRAP Report, for further details). It is observed that the rate of growth of personal vehicles is higher than other types. The average annual growth rate of vehicles is about 19.7%. On average, about 500 new vehicles are added in Delhi every day.

The main sources of air pollution in Delhi are buses, cars, auto-rickshaws, trucks and scooters/motorcycles. In 1993, there were about 47,800 cars/jeeps, 1,403,000 scooters/motorcycles, 11,400 taxies, 70,500 three-wheelers, 23,200 buses and 111,300 trucks. These data together indicate that about 2.1 and 3.6 million vehicles were active on the roads in Delhi during the period from 1993 to 2001 (www.delhimetrorail.com/corporates/ecofriendly/Chapter%201.pdf accessed 25th May 2009). The details of these vehicles are given in Table 3. Of this traffic, 65% comprised motorcycles and scooters, showing that motorcycles and two-wheelers had the largest share of the total traffic fleet. Therefore, a case study was undertaken to investigate the driving cycle of motorcycles in Delhi. The length of driving data collection was around 8 km. The survey was conducted in April 2009 in Delhi city. The map of the typical study area is given in Figure 3.

Table 3 Details of traffic composition in Delhi (thousands)

Year	Car/jeeps	Motorcycle/ scooter	Three wheeler	Taxi	Buses	Truck	Total
1985	1175	637	31	9	14	59	925
1986	8203	746	41	9	15	62	1076
1987	242	868	45	9	15	71	1250
1988	280	979	52	9	16	80	1416
1989	333	1083	58	9	17	90	1590
1990	384	1191	62	10	19	99	1765
1991	413	1253	65	10	20	102	1863
1992	440	1317	67	11	20	107	1962
1993	478	1403	70	11	23	111	2096
2001	957	2378	95	19	41	169	3658

Source: Delhi Transport Authority.

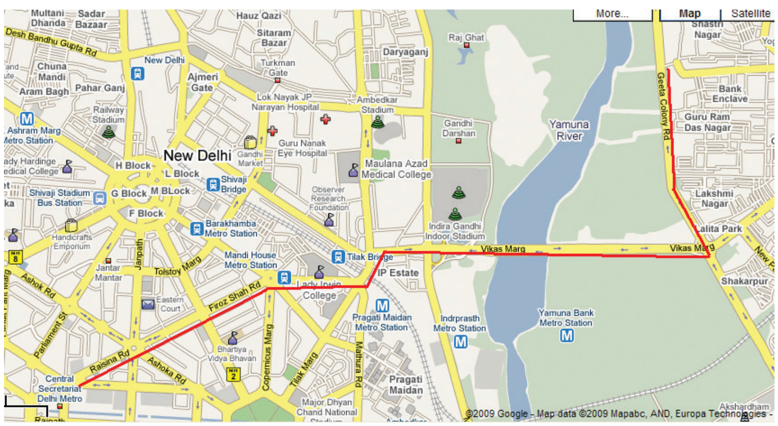

Figure 3 - Map of Delhi study area of motorcycle driving

4 Comparisons of Motorcycle Driving Cycle of Delhi with EMDC

The maximum speed (70 km h^{-1}) attained by Edinburgh drivers exceeding the speed limit (30 mph = 48 km h^{-1}), whereas Delhi motorcycle drivers never exceed 50 km h^{-1}. This indicates that although Delhi traffic has the same permitted speed limit (50 km h^{-1}), drivers never exceed this limit, but in Edinburgh, driving above the permitted limit is frequent (seen almost eight times in this typical driving). Acceleration and deceleration rates were higher in EMDC (almost 2-3 times) compared with Delhi. The reason was quite clear that the EMDC has motorcycles with higher engine sizes (>600 cc) than Delhi. Although average running speeds were almost same, this reflects the similarity in driving speed and speed limits on Delhi roads (see Table 4 and Figure 4). Positive kinetic energy of EMDC was very high. This shows the sport bike characteristic of Edinburgh as compared to Delhi motorcycles. Also the numbers of signals are also same. In vehicle operation modes, the percentage time spent in acceleration and deceleration modes of Edinburgh and Delhi was almost equal. Cruising time was found to be higher in Delhi motorcycle driving.

Table 4 Comparison of assessment parameter of EMDC and DMDC

Assessment Parameter	Units	Delhi	EMDC
Average deceleration of all deceleration phases (m s^{-2})	d	0.899606616	2.59
Average acceleration of all acceleration phases (m s^{-2})	a	0.729141069	1.28
Average speed of entire driving cycle (km h^{-1})	V1	34.35778043	33.5
Average running speed (km h^{-1})	V2	36.60903355	38.85
Mean length of driving period C (s)	C	847.8	769.63
Time proportion of driving modes in idling (fraction of time spent at speeds of 0-3 km h^{-1}) in %	Pi	1.037980656	1.51
Time proportion of driving in acceleration modes ($a > 0.1$ m s^{-2}) in %	Pa	46.82708186	44.45
Time proportion of driving in deceleration modes ($d < 0.1$ m s^{-2}) in %	Pd (m s^{-2})	42.73413541	46.87
Time proportion of driving modes in cruising modes ($a \le 0.1$ m s^{-2}, $d \le 0.1$ m s^{-2}) in %	Pc	9.43618778	7.24
Average number of acceleration and deceleration changes within one driving period	M	1667	1251
Root mean square acceleration	RMS		7.83
Positive kinetic energy (m s^{-2})	PKE	0.706590969	2.81
Total driving length (m)	L (m)	8054.710556	7313.59

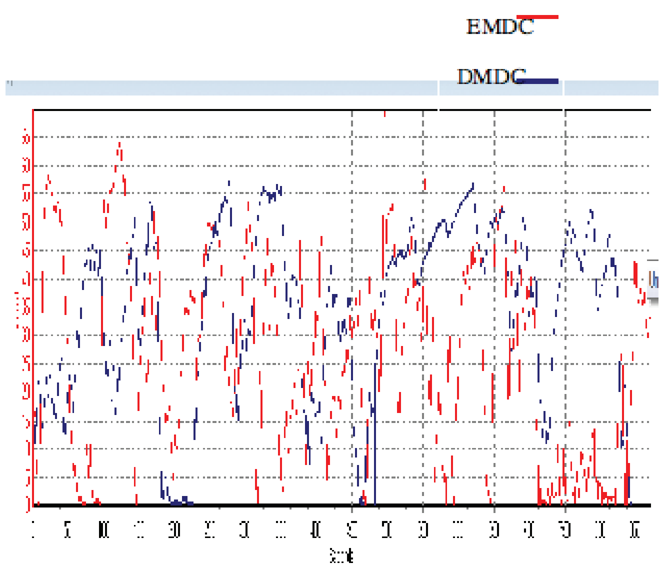

Figure 4 - Typical DMDC and EMDC

5 Summary

Driving cycles of motorcycles were investigated on different roads in Edinburgh city and its surrounding area: using advanced GPS techniques; a large amount of data on instantaneous speed under realistic road conditions was gathered. On the basis of these investigations, the driving cycles of motorcycles on different roads were analysed and developed for both urban and rural roads, which are important for emission estimation. Derivation of driving cycle requires synthesis of a large amount of driving data. The EMDC was constructed by synthesising the data of 44 trips across the north–south and east–west corridor of the city to represent the driving cycle of urban and rural conditions of the city. The developed EMDC for urban and rural areas was compared with existing regulatory driving cycles and driving cycles used for cars and motorcycle. There were significant differences observed across the different sets of parameters, such as time spent in different vehicle operating modes and rates of acceleration and deceleration. Moreover, a small investigation of the DMDC was undertaken. The results show that EMDC has higher acceleration and deceleration rates than DMDC. These findings are important for further efforts to control emission in urban and rural driving conditions.

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