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# DRIVING CYCLE FOR MOTORCYCLES IN MODERN CITIES: CASE STUDIES OF EDINBURGH AND DELHI

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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 (EMDC & DMDC) driving cycle (EMDC) that were developed through the analysis of experimental data. This data was 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 in Edinburgh were selected. In Delhi data were collected in East Delhi (Geeta Colony) to Central Delhi (Raisena Road). The data collected was divided into two categories of urban and rural roads in the case of Edinburgh while 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 in Edinburgh, the EMDC has a cycle length of 770 and 656 seconds for urban and rural trips, respectively, which was found more than ECE cycle length. Time spent in acceleration and deceleration modes were 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. In Delhi on the other hand, the DMDC has a cycle length of 847.5 seconds for the urban trips, which is higher than that of the EMDC length. The overall percentage time spent in acceleration in Delhi was higher than that of Edinburgh while the time spent in deceleration was lower in Delhi. The overall average speed in the case of Delhi was slightly higher than that of Edinburgh.

**Keywords:** Motorcycle driving cycle; Edinburgh; Delhi, GPS; Vehicle-operating modes

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## 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 performed to determine the driving cycles for private cars and light goods vehicle (LGV) as part of enhancing traffic management systems, determining fuel consumption patterns and reduce transport impacts on health (Lee et al., 2005; Tzirakis et al., 2006; Saleh 2007; Hung et al., 2007). 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 have increased by 37% from 1996 to 2006 in the UK and traveled around 5.2 billion vehicle–kilometers in 2006 with fleet of average age of 8.5 years (Compendium of Motorcycling Statistics, 2007, 2007). In Edinburgh, motorcycle ownership has almost doubled in the last 10 years (DVLA, 2006).

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

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) respectively. Euro 3 standards for mopeds (fitted with engines smaller than 50 cc) were also implemented from 2007 (EC, 2002). 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 (Ntziachristos and Samaras, 2000; Gkatzoflias, et al., 2007).

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 was collected by installing the equipment in motorcycles and by carrying out an emission surveys 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 while only urban trips were considered in the case of Delhi. Finally, for each of the EMDC and the DMDC for both urban and rural roads were produced by assessment of its parametric values were conducted. Comparisons of the results were made with a number of driving cycles including those of the WMTC, some driving cycles in Taiwan, Edinburgh driving cycle (EDC) and Economic Commission for Europe Driving Cycle (ECE).

## 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 results into more realistic driving data. Techniques like 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 employed for data collection of driving behaviour. These methods can also reproduce traffic flow very realistically under different real-world driving conditions (Fellendorf and Vortisch, 2000 and 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) have 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 was comprised of 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 PBs tracked these minor kinematics 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 were also used in assessment of deriving driving cycle by several researchers (Tzeng 1999, Hung 1999, Andre 2004, Tsai, 2003).

The mean value, standard deviation (SD) and coefficient of variations (COV) 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 done by calculating the absolute sums of the relative error ( $S_j$ ) then by selecting the driving cycle with minimum value of  $S_j$ . The relative error value for each of the parameters ( $\Delta_k$ ) is:

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

where  $k$  is an assessment parameter ( $k$  varies from 1 to 12) and  $\Delta_k$  is the value of the relative error for parameter  $k$ ,  $\bar{P}$  is overall mean value of parameters,  $P_{ijn}$  is a parameter with a value of a route  $i$  (between 1 and 5) and 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.

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

Route	Routes types	D (m s <sup>-2</sup> )	A (m s <sup>-2</sup> )	V1 (m s <sup>-2</sup> )	V2 (m s <sup>-2</sup> )	C (s)	P <sub>i</sub> (%)	P <sub>a</sub> (%)	P <sub>d</sub> (%)	P <sub>c</sub> (%)	M	RMS	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
SD	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
COV (%)	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 the drawn across all the 44 test runs for urban and rural section

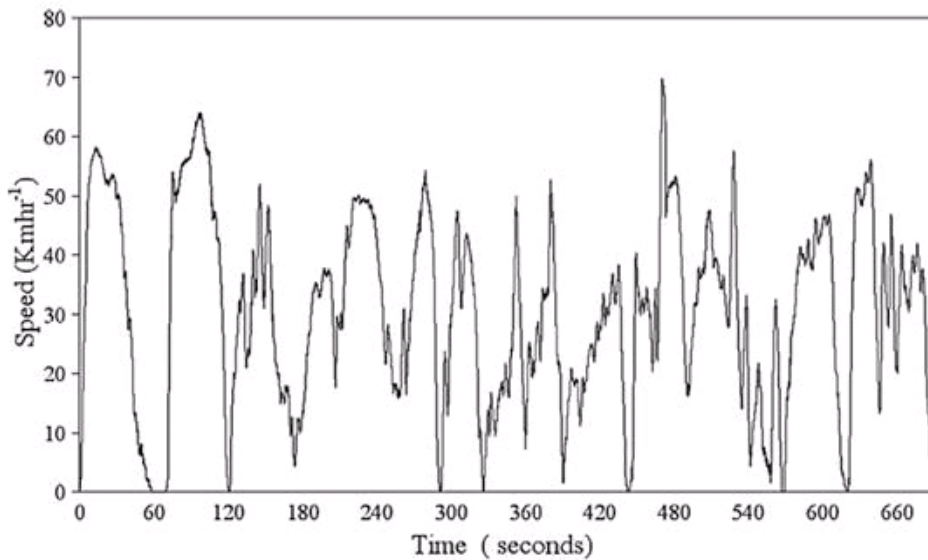
**Table 2** The sums of absolute relative errors of the assessment parameters for urban and rural routes.

Route	$D$ ( $m\ s^{-2}$ )	$A$ ( $m\ s^{-2}$ )	$V1$ ( $km\ hr^{-1}$ )	$V2$ ( $km\ hr^{-1}$ )	$C$ (s)	$Pi$ (%)	$Pa$ (%)	$Pd$ (%)	$Pc$ (%)	$M$	$RMS$	$PKE$	Sum of Absolute Error (%)
<i>Rural routes</i>													
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
<i>Urban routes</i>													
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.

The mean values of the key parameters are presented 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 (Tzeng, 1999). The average speeds of motorcycle in the urban and rural are  $33.5\ km\ h^{-1}$  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

**Figure 1** Driving cycle EMDC (urban)

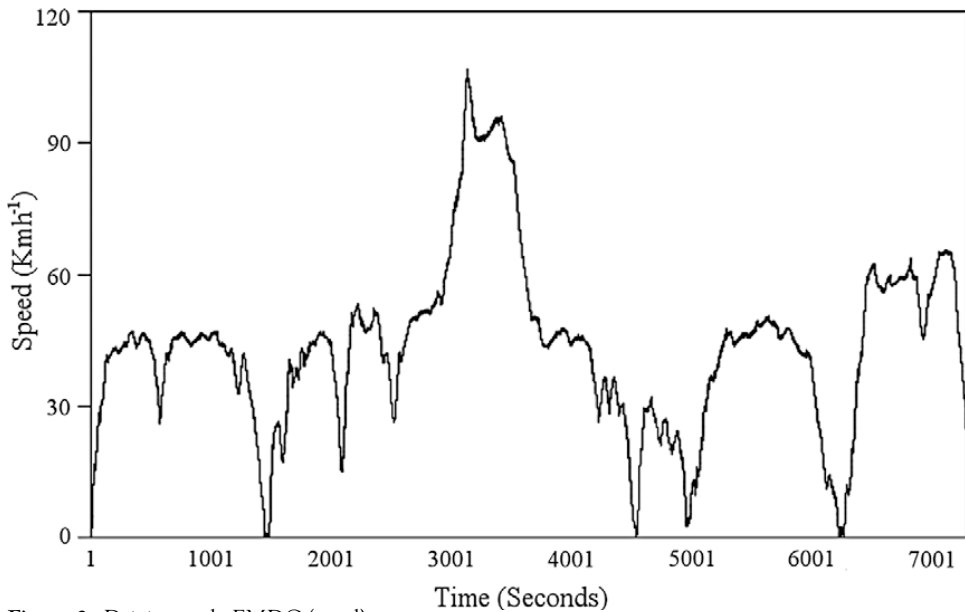


Figure 2 Driving cycle EMDC (rural)

were  $70 \text{ km h}^{-1}$  and  $120 \text{ km h}^{-1}$ . 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 km 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 ( $V_2$ ) and average speed of entire driving cycle ( $V_1$ ) were  $38.85$  and  $33.55 \text{ km h}^{-1}$  respectively. The values for urban EMDC were lower than those for rural EMDC. These differences were attributed to the higher speed limit ( $112 \text{ km h}^{-1}$ ) adopted by highway agency in UK for rural sections compared to urban ones ( $48 \text{ km h}^{-1}$ ). 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 ( $P_i$ ), acceleration ( $P_a$ ),

and decelerations ( $P_d$ ) are higher for urban sections than rural. Furthermore, time spent in cruise ( $P_c$ ) 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 as compared to only 40% on urban roads; again, seemingly due to the small number of traffic signals on the rural roads.

### MOTORCYCLE DRIVING CYCLE OF DELHI (DMDC)

During the course of the current research investigation of Delhi motorcycle driving cycle was carried out in Delhi (Saleh et al., 2009, Kumar et al, 2008). Rapid increase of motorcycle ownership in Delhi has resulted in high pollution in road traffic as well as congestion in cities. The vehicle population

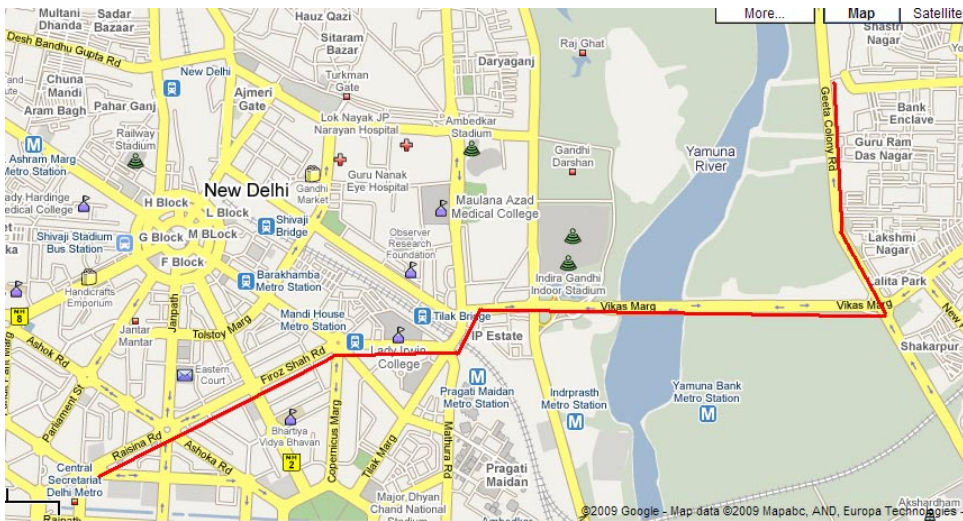


Figure 3 Map of Delhi study area of motorcycle driving

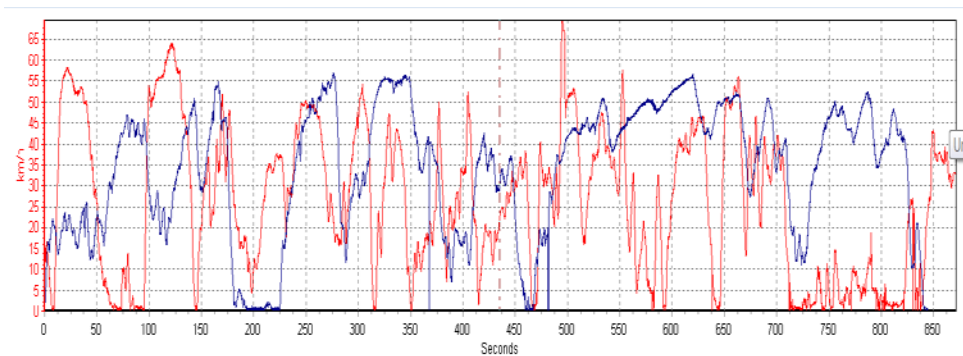


Figure 4 Typical Delhi MDC and EMDC

in Delhi is highest among all the metropolitan cities (Bombay, Calcutta, Delhi and Madras) in India. During 1985 to 2001 the total number has multiplied four times (see URTRAP Report, CRR 2004, 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 taxis; 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 (<http://www.delhimetrorail.com/corporates/ecofriendly/Chapter%201.pdf> accessed on 25 May 2009). The details of these vehicles are given in Table 1. Of this traffic 65% was comprised of motorcycles and scooters, showing that motorcycles and two-wheelers had the largest share of the total traffic fleet.

**Table 3** Details of traffic composition in Delhi (thousands)

Year	Car/Jeeps	Motor-cycle/ Scooter	3-Wheeler	Taxi	Buses	Truck	Total
1985	1175	637	31	9	14	59	925
196	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

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.

### COMPARISONS OF MOTORCYCLE DRIVING CYCLE OF DELHI (DMDC) TO EMDC

The maximum speed ( $70 \text{ km hr}^{-1}$ ) attained by Edinburgh drivers exceeding the speed limit ( $30 \text{ mph} = 48 \text{ km h}^{-1}$ ) while Delhi motorcycle drivers never exceed  $50 \text{ km h}^{-1}$ . This indicates that while Delhi traffic has the same permitted speed limit ( $50 \text{ km h}^{-1}$ ) drivers never exceed this limit, but in Edinburgh driving above the permitted limit is frequent (seen almost 8 times in this typical driving). Accelerations and deceleration rate was higher in EMDC (almost 2 to 3 times) compared to Delhi. The reason was quite clear: that the EMDC has motorcycles with higher engine sizes ( $>600 \text{ cc}$ ) 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). 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 were almost equal. Cruising time was found to be higher in Delhi motorcycle driving.

### 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 were 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 were 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



**Table 4** Comparison of assessment parameter of EMDC and DMDC

Assessment Parameter	Units	Delhi	EMDC
Average deceleration of all deceleration phases (m/sec <sup>2</sup> )	d	0.899606616	2.59
Average acceleration of all acceleration phases (m/sec <sup>2</sup> )	a	0.729141069	1.28
Average speed of entire driving cycle(kmh <sup>-1</sup> )	V1	34.35778043	33.5
Average running speed (kmh <sup>-1</sup> )	V2	36.60903355	38.85
Mean length of driving period C(Seconds);	C	847.8	769.63
Time proportion of driving modes in idling(fraction of time spent at speeds of 0-3 kmhr <sup>-1</sup> ) in %	Pi	1.037980656	1.51
Time proportion of driving in acceleration modes (a>0.1ms <sup>2</sup> ) in %	Pa	46.82708186	44.45
Time proportion of driving in deceleration modes (d<0.1ms <sup>2</sup> ) in %	Pd(m/sec <sup>2</sup> )	42.73413541	46.87
Time proportion of driving modes in cruising modes(a<=0.1ms <sup>2</sup> , d<=0.1ms <sup>2</sup> ) 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/sec <sup>2</sup> )	PKE	0.706590969	2.81
Total driving length(m)	L(m)	8054.710556	7313.59

rural areas were compared with existing regulatory driving cycles and driving cycles used for cars and motorcycle. There were significant difference 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 Delhi Motorcycles DMDC was undertaken. The results show that EDMC 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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#### BIOGRAPHY

**Dr. Ravindra Kumar** is a Scientist, Central Road Research Institute New Delhi. He is specialist in rural road network planning, GIS application and transport environment with experience of over 13 year and experience to work in UK, Australia, Bahrain and India. He has extensive experience of innovation and road development in diverse and complex category of roads including urban, rural, transport environment and micro-simulation. He has been a project leader for number of projects, representative of Student Union, has lectured in many distinguished universities and is a Task Force Member of IS/ISO 9001:2000 of CRRI. He has experience in handling many GIS related software such as Performance Box (GPS based), Arc GIS, Mapinfo, TransCAD, Geomedia, and micro simulation software such as VISSIM and Paramics. He has also

used GPS based instrument (Performance Box), Network Survey Vehicle procured from TSai International under ARRB, Australia to collect road condition and GIS based data. He has published many paper at national and international conferences and at academic journals.

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## REFERENCES

- Andre, M., 1996. Driving cycle development: characterization of the methods. SAE Paper 961112.
- Andre, M., 2004. The ARTEMIS European driving cycles for measuring car pollutant emissions. *Science of the Total Environment* 334–335, 73–84.
- Booth, A. E., Munner, T., Kirby, H., Kubie, J., Hunter, J., 2001. The Measurement of Vehicular Driving Cycle within City of Edinburgh. *Transportation Research Part D* 6, 209–220.
- Compendium of Motorcycling Statistics, 2007. Downloadable from: [www.dft.gov.uk/pgr/statistics/datatablespublications/vehicles/motorcycling/motorcyclingstats2007](http://www.dft.gov.uk/pgr/statistics/datatablespublications/vehicles/motorcycling/motorcyclingstats2007)
- Chen, K. S., Wang, W.C., Chen, H.M., Lin, C.F., Hsu, H.C., Kao, J.H., Hu, M.T. 2003. Motorcycle emissions and fuel consumption in urban and rural driving conditions. *Science of the Total Environment* 312, 113–122.
- Fellendorf, M. and Vortisch, P., 2001. Validation of the microscopic traffic flow model VISSIM in different real-world situations. *Proceedings of Transport Research Board, USA*, pp.1–9.
- Gkatzoflias Dimitrios, Ntziachristos L., Samaras Z., 2007. COPERT 4 Computer programme to calculate emissions from road transport – Users Manual version 5.0. Laboratory of Applied Thermodynamics, Mechanical Engineering Department, Aristotle University, Thessaloniki, Greece
- Hung, W.T., Tong, H.Y., Lee, C.P., Ha, K., Pao, L.Y., 2007. Development of a practical driving cycle construction methodology: A case study in Hong Kong. *Transportation Research Part D* 12, pp115–128. <http://www.delhimetrorail.com/corporates/ecofriendly/Chapter%201.pdf> accessed on 25 May 2009.
- Kumar, Ravindra Saleh Wafaa, and Kirby Howard., 2007. Towards development of driving cycle for motorcycle for Edinburgh. *Managing Knowledge, Technology and Development in the Era of Information Revolution World Association for Sustainable Development (WASD)*, Australia, ISBN (Print) 0-9551771-3-8 (Print), ISBN (ebook) 0-9551771-2-X (CD)
- Kumar, R., Saleh, W., Howard, K., 2008. Investigation of the driving cycle of motorcycles in Edinburgh – A Simulation study. *10<sup>th</sup> World Congress*

- on Environmental Health (Organised by International Federation of Environmental Health and Brisbane University), Brisbane, Australia, 11–16 May 2008.
- Lee, Chen-Chen., Wen, Yu-Cheng., Kang, Jou. Jaw., 2005. Motorcycle exhaust particles induce IL-8 production through NF- $\kappa$ B activation in human airway epithelial cells, *Journal of Toxicology and Environmental Health Part Volume 68, Number 17-18 / pp A1537 – 1555.*
- National Atmospheric Emissions Inventory (NAEI) Database UK., 2008. Downloadable from: [www.naei.org.uk](http://www.naei.org.uk)
- Ntziachristos, Leonidas., Mamakos, Athanasios., Samarasa, Zissis., Xanthopoulos, Anastasios., Lakovou, Eleftherios., 2006. Emission control option for power two wheelers in Europe, *Atmospheric Environment* 40 pp 4547–4561
- Ntziachristos, L., and Samaras, Z., 2000. COPERT III Computer programme to calculate emissions from road transport. Methodology and emission factors (Version 2.1). Technical Report No 49.-European Environment Agency, Copenhagen. <http://vergina.eng.auth.gr/mech/lat/copert/copert.htm>.
- Salah Wafaa (2007) Success and Failure of Travel Demand Management: Is Congestion Charging the Way Forward? *Transportation Research Part A: Policy and Practice* Volume 41, Issue 7, Pages 611-614
- Salah Wafaa, Kumar Ravindra, Kirby Howard and Kumar Prashant (2009) *Transportation Research Part D: Transport and Environment* Volume 14, Issue 5, , Pages 326-333
- Salah, Wafaa S, Nelson, John D., Bell, Michael G. H., 1998. Determinants of energy consumption: examination of alternative transport policies using the temis program, *Transportation Research Part D: Transport and Environment* Volume 3, Issue 2, 1 March 1998, Pages 93–103
- Scottish Transport Statistics No. 26., 2007. Downloadable from [www.scotland.gov.uk/Publications/2007/12/14120610](http://www.scotland.gov.uk/Publications/2007/12/14120610) – 17k
- Shafiepour, M., Kamalanh, H., 2005. Air quality deterioration in Tehran due to motorcycles, *Iran Journal of Environment and Health Science Engineering* Vol. 2, no. 3, 145–152.
- Shing-Hwa, Liu., Jei-Hui, Wang., Jiunn-Jye, Chuu., Shoei-Yn, Shiau Lin., 2002. Alterations of motor nerve functions in animals exposed to motorcycle exhaust. *Journal of Toxicology and Environmental Health Part A Volume 65, Number 11 / June 14, 2002*
- Tong, H.Y., Hung, W.T., Cheung, C.S., 1999. Development of a driving cycle for Hong Kong. *Atmospheric Environment* 33, 2323–2335.
- The City of Edinburgh Council, 2006. Updating and Screening Assessment Report, Downloadable from [www.edinburgh.gov.uk/internet/Environment/Environmental\\_health/Pollution/Air\\_pollution/CEC\\_air\\_quality](http://www.edinburgh.gov.uk/internet/Environment/Environmental_health/Pollution/Air_pollution/CEC_air_quality) – 22k
- Tzeng, G.H. and Chen, J.J., 1998. Developing a Taipei motor cycle driving cycle for emission and fuel economy. *Transport Research-D, Vol. 3 No.1*, 19–27.
- Tsai, Jiun-Horng., Chiang, Hung-Lung., Chun Hsu, Yi., Penga, Bo-Jun., Rong-Fang Hung., 2005. Development of a local real world driving cycle for motorcycles for emission factor measurements. *Atmospheric Environment* 39, 6631–6641.
- Tzeng, Hui-Ping., Yang, Rong-Sen., Tzuu-Huei, Ueng., Shoei-Yn, Lin-Shiau., Liu, Shing-Hwa., 2003. Motorcycle exhaust particulates enhance vasoconstriction in organ culture of rat aortas and involve reactive oxygen species. *Toxicological Sciences* 75, 66–73.
- Tzirkasi, E., Pitsas, K., Zannikos, F., Stournas, S., 2006. Vehicle emission and driving cycle: Comparison of the Athens driving cycle (ADC) with ECE-15 and European driving Cycle. *Global Nest Journal*, Vol. 8, No 3, pp 282–290.
- Tzirkasi, E., Pitsas, K., Zannikos, F., Stournas, S., 2006. Vehicle emission and driving cycle: Comparison of the Athens driving cycle

- (ADC) with ECE-15 and European driving Cycle. *Global Nest Journal*, Vol. 8, No 3, pp 282-290.
- Urban Road Transport and Air Pollution, Central Road Research Institute, Delhi 2003
- UK Government climate change policy for sustainable development –climate change bill final impact assessment, 2008. Downloadable from [www.defra.gov.uk/environment/climatechange/uk/legislation/pdf/ccbill-ia-final.pdf](http://www.defra.gov.uk/environment/climatechange/uk/legislation/pdf/ccbill-ia-final.pdf).
- Vasic, Ana Marija and Weilemann, Martin., 2006. Comparison of real-world emissions from two-wheelers and passenger cars. *Environment Science. Technology*. 40, 149-154.
- Saleh, W, Kumar, R and Sharma, A (2009) "Real World Driving Cycle for motorcycles: A Comparative Study between Delhi and Edinburgh". *World Sustainable Development Out Look 2009*. pp 211-220. Published by WASD, The Freeman Centre, University of Sussex, United Kingdom ISBN: 978-1-907106-05-7.
- Kumar, R., Saleh, W and Boswell, C (2009) "Onboard Emission Measurement of Motorcycles in Air Quality Management Area of Edinburgh". *World Sustainable Development Out Look 2009*. pp 145-154. Published by WASD, The Freeman Centre, University of Sussex, United Kingdom ISBN: 978-1-907106-05-7.