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Does Motorcycle Driving Behaviour Affect Emission and Fuel Consumption?

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Abstract

The behaviour of motorcycles driver is influenced by many factors, which include the personal characteristics (attitude, experience etc.) environmental (road geometry, traffic control etc.) and vehicle characteristics (performance, load etc.). Increased level of thrill, ability to filter in traffic and overtake ahead queue and higher engine power ratio creates aggressive driving behaviours for motorcyclist. This research is focussed on understanding the different level of driving behaviour and its impact on emission and fuel consumption. Experimental tests were carried out on Chassis dynamometer under typical Edinburgh driving condition.

A representative test track was created using a chassis dynamometer to assess the sensitivity of fuel consumption to a wide range of driving patterns. Three types of driving patterns were used based on the rate of acceleration and deceleration levels: average, calm and aggressive driving patterns. For each of these levels motorcycle test runs were carried out in the laboratory. The fuel consumption and emissions were measured at the same time of motorcycle test run and emission factors were predicted also using the TRL emission and fuel coefficients. As per normal driving and aggressive driving, there was little different found in HC, NOx and CO, whereas calm driving shows greater impact on emissions (about 15-17% lower) as compared to emissions emitted during aggressive driving. The results from this study suggest that, reducing speed by changing the driving style in cities would save the amount of fuel and produce lesser emissions. However, the results also show that on an individual basis, the fuel savings achieved from these behaviours would vary significantly as a result of reducing accelerations and/or reducing speeds.

Key Word: *emission, fuel consumptions, driving behaviour and style, motorcycle*

1. Introduction

Aggressive driving behaviour is complex and a global issue (Aggressive driving is increasing due to lack of responsible driver behaviour, reduced level of enforcement and more travel in congested urban. 70 per cent of drivers in the European Union admitted to showing aggressive behaviour and also reported that there is increased in aggressiveness of drivers (*i.e.*, 65% respondent the respondents in Russia, 75 per cent of the respondents in the EU and 80 per cent of the respondents in the United States agreed (UNECE, Background paper, 2004). Speeding or driving 10 mph or more over the speed limit has been considered one of important factor as aggressive driving that leads to high acceleration and deceleration in urban stop and go conditions. Though motorcyclist in United Kingdom try to follow speed limit, the percentage of motorcyclist exceeding the speed limits in motorways goes up to 49% and 20% of them exceed the limit by 10mph or more (Saleh, 2010). Higher speed and aggressive driving not only contribute to accident but its impact on emission and fuel consumption of both petrol and diesel vehicle has been reported by many researchers for car and LGV (Bery, 2010, Gonder 2012, Boulter *et*

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al., 2009). Depending on the type of road and vehicle technology, fuel consumption may increase by up to 40% for aggressive driving compared to normal driving. Aggressively driven cars contained considerably more polluting chemicals and in the case of carbon monoxide the increase was as much as eight times greater than normal driving (UNECE, Background paper, 2004).

Sensible driving can lower gas mileage by 33% at highway speed and 5% in town which has significant impact on cost. Each 5mph over 50 mph cost an additional $24 per gallon (US Depart of energy, 2013). Stricter (2012) found that more efficient driving behaviour could reduce fuel use by as much as 20% on more aggressive stop-and-go drive cycles. If a driver is considered moderate in his driving style, an improvement anywhere from 5-10% can be seen in National Renewable Energy Laboratory (NREL). Higher speeds correlate with more fuel consumed Gonder *et al.*, (2012). Eco-driving of light duty truck reduces fuel consumption by as much as 5 to 10 percent (Berry 2010). Driver has more influence over fuel economy than any other single factor (Joyne, 1965). Driving behaviour had a greater influence on petrol-fuelled than on diesel-fuelled cars. For city driving intense traffic increased fuel consumption by 20–45%. The increase in fuel consumption and emissions during rush hours were the highest on roads, with increases between 10 and 200% (Vlieger, I *et al.*, 2000). In general overlong terms, 5 to 10 % reduction in fuel consumption is feasible through eco driving and its percentage depend on combination of (i) people willingness to drive differently and the sensitivity of special vehicle to changes in driver aggressiveness. Bery (2010) reported that reducing velocities during highway driving would save roughly the same amount of fuel as reducing acceleration during all drivers and reduction will depend on individual driver behaviour. The greater amount of fuel saving achieved if aggressive drive at moderate speed. Most of studied focused on car and light duty truck and failed to address the issue of motorcycle emission and fuel consumption under different driving pattern under in European context. Warren Spring laboratory cycle which are used for emission test in UK does not reproduce aggressive of driving hence miss high acceleration of roads (Boulter *et al.*, 2009)

Motorcycles are convenient to use as private mean of transportation and every year is becoming more popular around Europe, and United Kingdom (TZENG, 1998, Duffy, 2004) ownership of which is almost doubled in Edinburgh in a decade. However, the main concern is that their emissions are higher rates (*i.e.*, per km (CO, HC and NOX) than that of a patrol car passenger so on of important pollution source in most urban areas. Emissions of HC and NOx are precursors of Ozone formation through photochemical reactions and the presence of the sunlight (Chen, 2003).These emissions are dangerous to human health (Tsai, 2003). Impact of aggressive driving shows that the average acceleration and deceleration are higher than $0.765 m/s^2$ European Driving Cycle in Taiwan (TZENG, 1998). Speed-dependent emission factors are provided by Atmospheric Emission Inventory, UK (NAEI UK), there are no emission factors available in the literature for motorcycles accelerating under different driving behaviour for motorcycles. NAEI UK shows that motorcycles have almost double emission factors of NOx and HC (g/km) than petrol cars (Saleh *et al.*, 2009 and Kumar *et al.*, 2011). Various researchers measured emission factors of several pollutants such as CO, HC and NOx from various types of vehicles including: passenger cars and heavy duty trucks using the dynamometer. Very few studied have been carried out for small engine size motorcycles (Tsai, 2003, Chen 2003). However, motorcycles are different because they are driven differently than the four wheeled automobiles and have different driving speeds, driving behaviour, and they deserve more research focus (Chen, 2003).

Driving pattern in United Kingdom significant differs due to size of motorcycle driven larger than 550 cc, weight power ratio, purpose of use in United Kingdom as compared to many Asian countries Taiwan, China, Vietnam, India, Philippines *etc.*, (Kumar *et al.*, 2011, Saleh *et al.*, 2009). The amount of fuel that a vehicle consumes in travelling any

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given distance depends on many parameters such as; the driving cycle, how aggressively the vehicle is driven, the load applied to the engine, state of maintenance, tyre inflation and use of air conditioning *etc*. It is impossible to know about all these parameters for every vehicle on the road and averages have to be used for what are in fact quite variable rates of fuel consumption for different groups of vehicle types (Tsagatakis, *et al.*, 2009).

Furthermore, motorcyclist emission factors during acceleration and deceleration under different types of driving are crucial in urban traffic simulation, environmental impact models and fuel economy. One of the most obvious reasons for improved fuel economy and cost saving as there is continuous increase in fuel cost in United Kingdom. By reducing the amount of fuel today's vehicles burn cost of fuel and emissions are both reduced along with cost of operation at fleet level (Stichter, 2012). This reduction of emissions is not only a requirement of the government but also an obvious step in the right direction for improving the environment and the health of the public. Fuel economy and emission management are becoming more evident and amongst the major factors which are influenced by the type and style of driving (Erricson, 2005 and Stichter, 2012). Therefore, there is a great need to understand the driving behaviour of motorcyclist in particular, which is related to aggressive acceleration and deceleration and speed.

For United Kingdom, fuel consumption and emission factors used in the NAEI calculations are polynomial functions expressing the relationship between fuel consumption rate and average vehicle speed for each class of vehicle. These are based on measurements of fuel consumption and emission rates for samples of in-service vehicles taken off the road and tested under controlled laboratory conditions over a range of different operational drive cycles. There are other driving cycle such legislative motorcycle driving cycle, Harmonised World Wide Type Approval Test Cycle for Motorcycle-World Motorcycles Test Cycle (WMTC), New European driving cycle (NEDC) (see details Barlow *et al.*, 2009), Edinburgh Motorcycle driving cycle(EMDC)(see (Saleh *et al.*, 2009 and Kumar 2011) good to address emission certification and understand represented real world driving emission (DfT, 2010b) but failed to address emission at different level of accelerated driving and emission and fuel consumption on routes. Therefore, an approach to investigate the relationship between driving behaviour, motorcycle's performance and emissions is to observe various emission rates while driving aggressively, normally or calmly on same routes number of time has been proposed in this paper. The role of motorcycle performance is particularly interesting due to the recognized trade-off between vehicle performance and certified fuel consumption and because of the known fact that more powerful motorcycles are capable of performing more aggressive driving also.

This paper present results of the effects of different driving behaviour aggressive, normal and calm, on motorcycle emissions and fuel consumptions by testing a motorcycle running on a chassis dynamometer under controlled conditions in typical Edinburgh typical driving cycle. There was limitation in selecting corridor length because of Chassis dynamometer, measurement of fuel due to fuel sensor, therefore validation was result of made with TRL database. Section 2 of this paper deals with experimental design, Section 3 presents about driving characteristic adopted on Chassis dynamometer and Section 4 present result and discussion and Section 5 present conclusion.

2. Experimental Design

2.1. Corridor Identification, Creation and its Characteristics:

The motorbike driving cycle is created in order to use it in a computer simulator and also test them on the dynamometer (Kumar, 2009). Due to limitation of chassis dynamometer, original corridor (length 4.1 km) goes from York Place and Broughoum Street to Morningside Holy corner road under Air Quality Management Area (AQMA) in

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Edinburgh in the city centre has been modified upto 2.5 km (from Edinburgh Napier University in 10 Colinton Street to the end of Lothian Street. Figure 1 shows the driving route that is marked in blue where point A shows the initial point and B the end of the corridor. Point A is Edinburgh Napier University (Merchiston Campus) in and point B is Princess Street at the end of Lothian Street. This entire route is very busy and it has a number of signalised and priority traffic junctions. However, it is important to mention that in this study, characteristic of those junction are not going to be analysed because there are many unknown parameters and variables such as the cycle times for various junctions, traffic flows, *etc*.

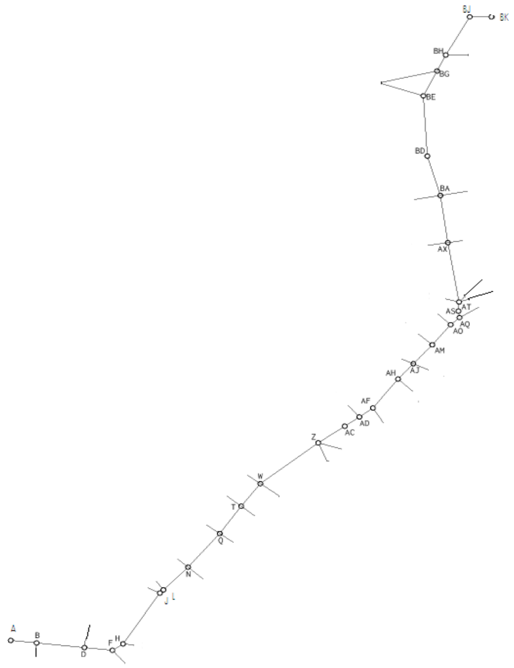

Figure 1. Detailed Motorbike Driving Cycle Route for Dynamometer Test

Table 2 shows the distance from point to point and the type of junction at each point of the route and also a traffic references for calculations on the speed that are going to be used later.

2.2. Test Apparatus

Chassis Dynamometer: The dynamometer used in study is Dyna Pro and the software Dyna Run V3 as shown in Figure 2. The dynamometer is very useful because it records the speed and time of the each run in different files and they can be analyse later using excel. It has some limitations that are going to be mention in a different section. The dyno software has chronometer screen showing speeds when driving the motorcycle. The dynamometer can be useful to measure the emission factor by simulating a real corridor but it does not consider real issues like wind, traffic or junctions. The dynamometer takes measures every 0.007 seconds. It is important to mention that all runs were done with the motorcycle's motor warm (hot condition).

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Figure 2. Chassis Dynamometer for Motorcycle Emission and Fuel Testing

Gas Analyser: The gas analyser used is OmiScan Gas of model year 2008. This equipment measures the exhaust emissions from vehicles that use petrol and in this case the motorcycle from the lab. The gas analyser has different options of live readings and measuring CO, CO2, NOx, HC and O2 apart from the AFR. It is important to calibrate the equipment before using it, nevertheless the equipment calibrate itself after and before taking measures. The gas analyser takes measures every 0.5 seconds. Rate of logging data from the dynamometer and the gas analyser are not synchronized in time as the dynamometer records data at every 0.007 sec and the gas analyser logs data at every 0.5 seconds. So the required data was filtered at 0.5 second interval from the dynamometer and the gas analyser. Also the time lag between start of chassis dynamometer and analyser was eliminated by repeating more number of experiments and discarding the first measured data set.

Motorcycle: The motorcycle used in the dynamometer has the following specification:

The specifications are useful because the TRL emission and fuel coefficients are based on these specifications to calculate the emission factors.

2.3. Creation of Driving Cycle for Emission and Fuel Measurement on Chassis Dynamometer

Definition of driving style were made in three category of driving aggressive, normal and calm based on city driving speed and driving pattern. The detailed of driving cycle and its characterisation is provided in next section.

2.4. Fuel Consumption Measurement by Volumetric Tank: Volumetric tank was used to measure fuel consumption in this study. 1000ml fuel was filled and then the motorcycle was driven at 10mph for a period of 2 minutes and then switched off and the fuel was measured. The procedure was repeated for each speed used in the corridor at 20, 25, 30 and 35 mph. The number of repetitions was six in most of the cases. Equation 3 is used to change units of the emissions from % or ppm to g/km. The units from these results are (l/m) and we need (g/sec) to convert then equation 3 is used as follows

$$\text{fuel mass}\left(\frac{\text{g}}{\text{sec}}\right) = \text{fuelconsumption}\left(\frac{\text{l}}{\text{m}}\right) \times \text{fuel}\,\delta \times \frac{1\text{min}}{60\text{sec}} : \textbf{\textit{Equation 1}}$$

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3. Results and Discussion

3.1. Characterizing Driving Aggressiveness

The average speed limits for traffic in the urban and rural areas are 33.5km/h and 49.73km/h but in some cases drivers exceeded the regulatory speed limits (Kumar, 2009). This is why in this study an upper speed limit of 35mph (56km/h) which is 5mph more than the regulatory limit (30mph) is assumed. The speed was based on behaviour of traffic on the corridor at noon times. Table 2 shows the distances between junctions, the type of junction and also a traffic references for the calculations of the speeds. The speed limit during the whole cycle is 30mph *i.e.*, 48km/h in the representative the study area. For each element of the section, initial and final speeds were given in order to allow detailed modelling.

Four criteria, ((i)Can be calculated based on only driving pattern and vehicle characteristics,(ii)Reflect driving style,(iii) Correlate with fuel consumption, and emission (iv) Are normalized by vehicle mass most popular type of engine size in United Kingdom. These criteria were selected to maximize the utility of the aggressiveness factors in answering the recognizing the significance of mass in fuel consumption, in order to be more comparable across vehicles the aggressiveness factors should be mass normalized. A proper engine size 599cc shows typical available engine size in United Kingdom for motorcycle (DFT, 20013). In developing these aggressiveness factors, a range of options were considered. However, as average speed and wheel work, together, can illuminate and predict fuel consumption. The aggressiveness factors rely on these parameters. In addition, because fuel consumption differs at different speed bands.

A separate speed band were defined for each for 0-20, 20-30 and 30-40mph. The separating speeds (20 and 45 mph) were selected by first choosing initial values based on the trends identified in then fine tuning them to optimize the fit of the three aggressiveness factors. Speed traces are sorted into these speed bands based on average speed. For simplicity, they have been given the names of “Calm “Average also normal driving” and “aggressive” driving. Though aggressive driving is difficult to define because of its many different manifestations but having a clear definition is important for police and legal action against it to succeed. In this study the following values have been assigned to define the different types of driving (Tong, 2005):

a) average driving: 0.73 m/sec^2 acceleration and -0.88 m/sec^2 deceleration,

b) Calm driving: 0.55m/sec^2, acceleration and -0.67 m/sec^2 deceleration,

c) Aggressive driving: 0.98 m/sec^2 acceleration and -1.19 m/sec^2 deceleration

For the whole experiment 1st gear was used for speed range from 0 to 20mph, 2nd gear from 20 to 30mph and 3rd gear from 30 to 40mph. The average accelerations and decelerations were modified by (+/-)10, 20 and 30% for each case for the aggressive and calm driving behaviour. This was termed as aggressiveness factor for driving. For the aggressive driver the new acceleration is the average plus 10 or 20 or 30% and for the calm driver is the average minus 10 or 20 or 30% value as shown in Table 2. The derived driving cycle based on this assumption is shown in Figure 3.

The corridor is divided into two divisions and the time for each section is shown in Table 2. Calm and average behaviour were taken in the same day; 10 repetitions for average and calm driving were done but unexpected results for average driving were shown and this test was done again in a different day. Besides that, one test for fuel consumption was also conducted and a test for average speed in each driving behaviour following the same pattern of the corridor and respecting the times were carried out.

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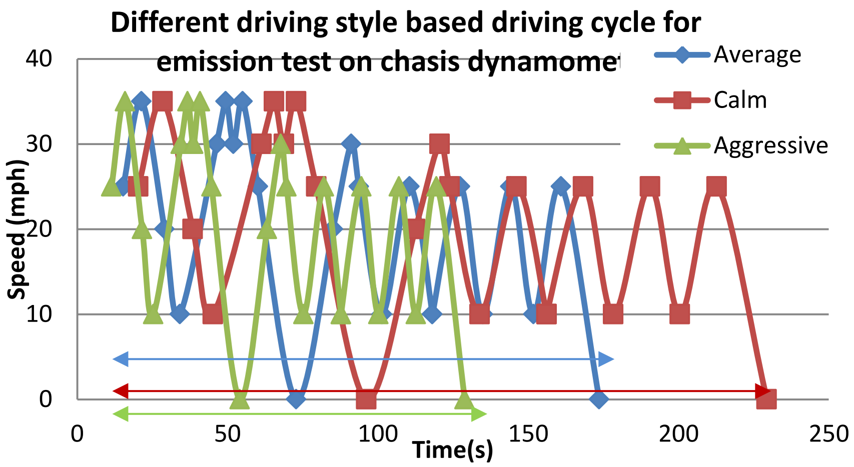

Figure 3. Different Driving Cycle Due to Change in Driving Style

Table 2. Change of Speed on Chassis Dynamometer on Different Type of Driving

Test section Element	Length (m)	Junction	Traffic	Initial Speed (mph)	Aggressive driving			Calm Driving			Average driving		
					Final Speed (mph)	Time spent (S)	Time Spent (s)	Final Speed (mph)	Time spent (s)	Time Spent (s)	Final Speed (mph)	time (s)	Time Spent (s)
A-B	57	Intersection	Fast	0	25	11	11	25	20	20	25	15	15
B-D	106.1	Intersection	Fast	25	35	16	5	35	28	8	35	21	6
D-F	61.9	Intersection	Fast	35	20	22	6	20	38	10	20	29	8
F-H	28	Traffic light	Fast	20	10	25	4	10	45	7	10	34	5
H-J	146.9	Intersection	Moderate	10	30	34	9	30	01:01	16	30	46	12
J-L	11	Intersection	Moderate	30	35	37	2	35	01:05	4	35	49	3
L-N	77.1	Intersection	Moderate	35	30	39	2	30	01:09	3	30	52	3
N-Q	107	Intersection	Moderate	30	35	41	2	35	01:13	4	35	55	3
Q-T	81.1	Intersection	Moderate	35	25	45	4	25	01:20	7	25	60	5
T-W	68.9	Traffic light	Moderate	25	0	54	9	0	01:36	17	0	01:13	13
AC-AD	39	Intersection	Slow	0	20	9	9	20	16	16	20	12	12
AD-AF	36.9	Intersection	Moderate	20	30	14	5	30	24	8	30	18	6
AF-AH	89	Intersection	Moderate	30	25	16	2	25	27	3	25	21	3
AH-AJ	50	Traffic light	Slow	25	10	22	6	10	37	10	10	29	8
AM-AO	61.9	Traffic light	Slow	10	25	29	7	25	49	12	25	38	9
AO-AQ	25.9	Intersection	Moderate	25	10	35	6	10	59	10	10	46	8
AQ-AS	15.8	Traffic light	Moderate	10	10	35	0	10	59	0	10	46	0
BD-BE(0)	145.4	Traffic light	Moderate	10	25	42	7	25	01:11	12	25	55	9
BD-BE	145.4	Traffic light	Moderate	25	10	48	6	10	01:21	10	10	01:03	8
BE-BH(0)	110	Traffic light	Moderate	10	25	55	7	25	01:33	12	25	01:12	9
BE-BH	110	Traffic light	Moderate	25	10	01:01	6	10	01:43	10	10	01:20	8
BH-BJ(0)	106.1	Traffic light	Moderate	10	25	01:08	7	25	01:55	12	25	01:29	9
BH-BJ	106.1	Traffic light	Moderate	25	0	01:17	9	0	02:12	17	0	01:42	13

3.2. Interpretation as Accelerations and Speed

In addition to providing a tool to quantitatively compare driving patterns, each of the three aggressiveness factors provides insight into the driving behaviours that most impact fuel consumption in that speed band. For city driving, this is clearly accelerations. Figure 4 shows instantaneous aggressiveness factors for the Honda Motorcycle over a range of accelerations and city speeds. This figure is for illustrative purposes only to help interpret city driving. It is not a look-up table of aggressiveness factors, which are based on average driving, not instantaneous driving.

3.2.1. Comparison of Speed and Acceleration of Aggressive Driving and NEDC

Another very common approach is to determine the percentage of a driving pattern or driving data that falls outside the range of a specific drive cycle, most often the New European driving cycle (NEDC) used for driving cycle pattern used on chasis dynamometer was evaluated. New European driving cycle has constant rate of acceleration and deceleration. Such type of driving cycles are certainly not observed in real world. Often, the maximum acceleration and speeds of a collection of driving, patterns or of a particularly drive cycle are plotted along with the NEDC cycle to demonstrate these differences graphically. Figure 4 shows the outer bounds of the NEDC and aggressive driving cycle shown in red colour along with the maximum accelerations and velocities. It was found that still it was not possible to reach acceleration and speed but within the various driving pattern calm driving have lower acceleration and speed compared with aggressive, average driving.

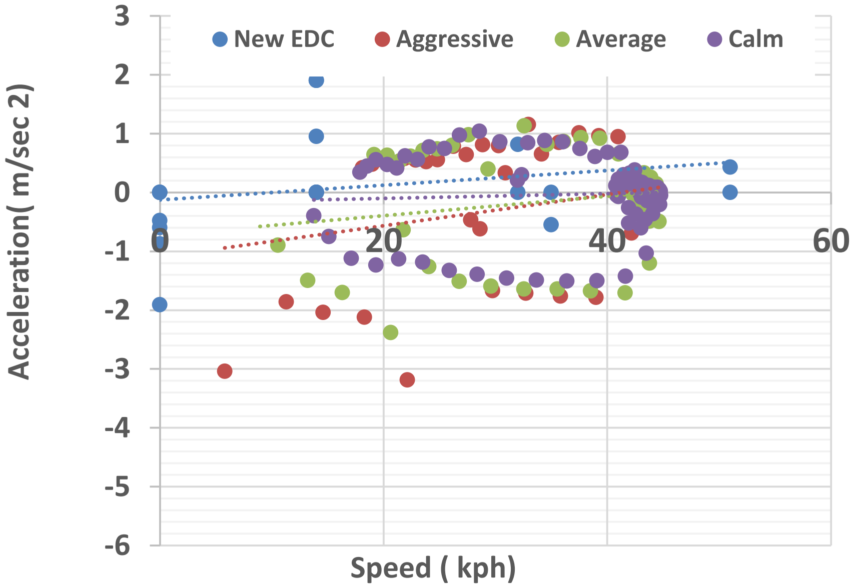

Figure 4. Comparison of Aggressive Driving Undertaken for Emission Test Under Different Level of driving and NEDC

The results indicate the complexity driving patterns which has significant impact on fuel consumption and emission. According to Ericsson (2001), the driving pattern variables that have significant increased effects on fuel consumption, besides strong acceleration, are: increased proportion of time spent idling, increased rpa, increased proportion of time at speeds <15 km/h and decreased proportion of time between 50 and 70 km/h. Other variables that have significant increased effects on fuel consumption are number of oscillations/100 m, late gear changing from gears 2 and 3 and high engine

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speed. Those variables are not analysed in this study. The parameters with the most significant effects on traffic-related emissions are strong acceleration and rpa.

Figure 5 shows the percentage time spent under different driving style (aggressive, calm and average or normal). In all the case time spent in driving for aggression is found lower. Maximum time spent were in speed range 10-30mph and 20-30 mph and minimum time spent during driving is for speed range 30-35 mph. For route many parameters that affected the fuel consumption but time spent in acceleration and deceleration is one of the important parameter affect over all fuel consumption and emissions (Ericson, 2001). There is decrease portion of time spent in speed range 30-35 which reflection of the fact that the majority of vehicles are most fuel-efficient in the range 30–35 km/h. The result indicates that the combination of several driving style factors is more important than one single factor.

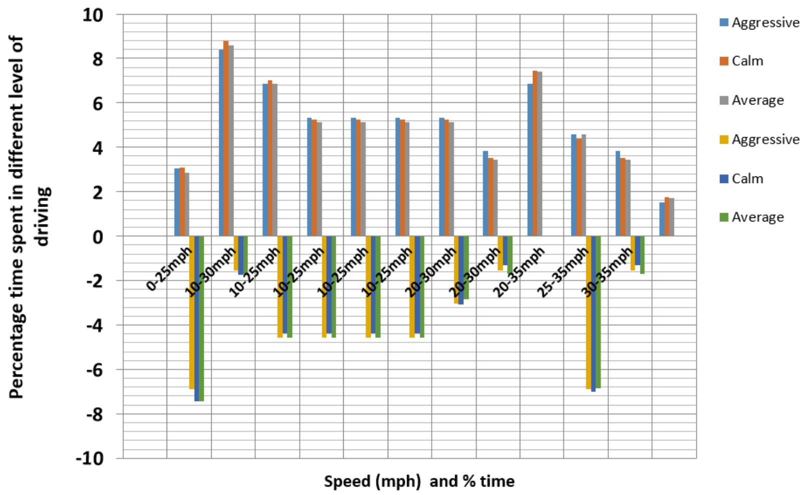

Figure 5. Time Spent in Driving in Acceleration and Deceleration for Section

3.3. Impact of Type of Driving with Speed Change on Emission:

Table d show the emission factors for the speeds selected on the corridor for the simulated calm, average and aggressive driving behaviours. According to the Centre for Science and Environment (CSE), the quantity of all three major air pollutants (Carbon oxides, hydrocarbons, and nitrogen oxides) drastically increases with reduction in motor vehicle speeds. For example, at a speed of 75 km/h, emission of CO is 6.4gm/veh-km, which increases to 33.0 gm/veh-km at a speed of10 km/h. Similarly, emission of hydrocarbons, at the same speeds, increases by 4.8 times from 0.93 to 4.47 gm/veh-km (Singh, 2005).

3.3.1. Overall Variations in Emission Factors for Different Types of Driving:

Emission measurements were done on three different driving styles as mentioned in Table 2. The value of emissions converted into gm/km for different driving styles are for carbon monoxide, NOx and Hydrocarbon. The graphical results show the effect of driving style on emissions. It was found that as the speed reduces from 32 to 16 km/hr, there is an increase in CO, HC and NOx whereas CO_2 decreases at this speed. Due to aggressive style of driving, there was significant impact on HC, CO and NOx emissions. However, the calm driving increase HC emissions and reduce CO_2 at lower speed of 16 km/h and increase CO_2 at higher speed.

Table 3 shows the variations in emission factors for average, aggressive and calm driving. From the table it is clear that there is no much significant difference in average and aggressive driving, whereas emission factor in aggressive driving has higher emissions compared to calm driving for CO, HC and Nox. Emission factors during calm driving for CO2 and O2 was higher than aggressive driving. But when it was compared with regulatory standard then it was found that emissions generated due to aggressive, calm and average driving for CO, HC and NOx is lower than regulatory driving. It means the test motorcycle is confirming the regulatory requirement of Euro 2 standard norms. In aggressive driving, the acceleration is larger than 78% to calm driving. Even at average similar speed 43.5, 43.8, 43.9 kmph, calm driving, average driving and aggressive driving has impact on emission. So economic driving behaviour should be adopted for emission and fuel saving.

Table 5 shows that above model has R^2 value is higher than 0.5 exception is hydrocarbon in average driving condition. The HC emission reflect there is data issue some time carbon deposition on sensor cause issue with data. Although we did another validation of the result with Transport Research laboratory (TRL) equation to get the emission factors for different speeds in different vehicles is shown in Equation2

$$\mathbf{y} = \frac{\mathbf{k}*(\mathbf{a}+\mathbf{bx}+\mathbf{cx^2}+\mathbf{dx^3}+\mathbf{ex^4}+\mathbf{fx^5}+\mathbf{gx^6})}{\mathbf{x}} \qquad \text{Equation 2}$$

Where y is the emission factor in (g/km), x is the speed in (km/h) and k, a, b, c, d, e, f and g are the coefficients depending on the type of vehicle. For this specific case the coefficients of a motorcycle Euro II is used, which is same to motorcycle emission standard tested in the laboratory. The coefficient can look into (Boulter, 2009) for speeds between 5 and 140 km/h for CO, HC NOx, corrected CO_2 respectively. This data and the speeds from the corridor is the only data needed in order to calculate the emission factors

Table 3. Over all Variations in Emission Factors for Different Styles of Driving

Characteristics	Style of driving	Emission factor (g/km) (CO)	Emission factor (g/km) (HC)	Emission factor (g/km) (NOx)	Emission factor (g/km) (CO2)	Emission factor (g/km) (O2)
Driving as in Edinburgh	Average	0.275757	0.002913	0.003469	7.989519	0.714553
	Aggressive	0.275763	0.002227	0.003465	7.952273	0.674155
	Calm	0.239111	0.001892	0.003135	8.069811	0.826196
Regulatory Standard	Euro 2	5.5	1	0.3		

If now we focus just in the experiment and compare the emissions of calm and aggressive driving behaviour the results are positive because aggressive driving has higher emission factors than calm driving behaviour, as a result we can say that driving behaviour is important to consider when analyzing results. The emission factors were also calculated with reference to TRL report and equation as mentioned in equation2 (Boulter, 2009) above. The percent error or deviations of emission factor from TRL (as normalised) to current three different driving styles adopted are shown in Table 4.

Table 4. % Errors in Emissions Compared to the TRL Report from Laboratory

Speed (km/h)	CO			HC			NOx			CO_2		
	CD	ND	AGD	CD	ND	AGD	CD	ND	AGD	CD	ND	AGD
%	%	%	%	%	%	%	%	%	%	%	%	%
40	0.992	1.027	0.992	0.983	0.992	0.985	0.964	0.968	0.964	0.931	0.94	0.934
56	0.985	1.017	0.978	0.991	0.996	0.985	0.963	0.964	0.971	0.933	0.941	0.944

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32	0.972	1.021	0.965	0.991	0.997	0.984	0.94	0.932	0.915	0.917	0.925	0.923
16	0.976	1.036	0.946	0.866	0.91	0.908	0.932	0.927	0.885	0.974	0.961	0.945
48	0.99	1.021	0.989	0.99	0.994	0.975	0.958	0.96	0.959	0.932	0.94	0.937
56	0.986	1.016	0.989	0.991	0.996	0.984	0.963	0.959	0.959	0.933	0.94	0.936
48	0.981	1.014	0.98	0.99	0.994	0.982	0.949	0.948	0.94	0.926	0.935	0.931
56	0.979	1.012	0.975	0.959	0.95	0.979	0.962	0.952	0.946	0.947	0.958	0.944
40	0.976	1.015	0.969	0.984	0.982	0.97	0.937	0.932	0.905	0.933	0.941	0.928

CD: Cam Driving, ND: Normal or Average Driving AGD: Aggressive Driving

From Table 4 it is observed that in most of the cases, emission factors from TRL equation is coming higher to chassis dynamometer at speed coefficient used from TRL report. Table 4 shows the percent error for CO, HC, NOx and CO2 for three different driving styles. The table also shows the percentage errors of the experimental data compared to the TRL report and in all cases except one the error is higher than 0.9 %. At speed 16km/h the error is 85% for calm and 0.91 and 0.9% for normal and aggressive.

3.4. Fuel Consumption

Figure 9 shows the observation of fuel measured at different speed. A fuel flow meter was installed in order to have accurate measures of fuel consumption during each run. However, the flow meter was not working the way it should work and it was not constant in each run for recorded data. The volumetric tank was used in this study instead; 1000ml fuel was filled and then the motorcycle was driven at 10mph for a period of 2 minutes and then switch off in order to see how much of the fuel was consumed during that time. This same procedure was repeated for each speed used in the corridor at speed of 20, 25, 30 and 35 mph. The number of repetitions were 6 in most of the cases but if in more than three repetitions were the same no more repetitions were done. At the end the data collected is organized in a table and is used to change units of the fuel consumption to (l/m) and we need (g/sec) so this equation is used for the conversion as mentioned in the methodology. The test was not fully completed because of non-availability of the fuel sensor. However, from the few tests, it is found that due to increase in speed from 10 to 35 mile per hr, there is an increase in the rate of fuel consumption from 0.33 second to 0.51 gm/sec.

3.4. Development of Eco-Driving Model for Emission and Fuel Consumption

Eco driving is a new approach to driving style developed since the mid '90s and in the last decade has been the subject of some initiatives and projects at European level to define it precisely. The latest of these European initiative have been done on many project. Beside Europe the growth of the eco driving awareness is verified by many agencies worldwide. The basic driving rule is characterized as eco-driving “rules” to adopt an anticipatory driving style avoiding unnecessary accelerations and braking. These situations are the ones, into a driving cycle, consuming more emission and fuel consumption and use the engine as efficiently as possible. As the engine efficiency increases with the engine load and the internal friction. Loss decreases with decreasing the engine speed, the combination of high loads and low engine speeds allows to spend less fuel for the same power supplied by the engine (Alessandrini, et al. 2012). In this eco driving has been observed and emission model developed as shown in Figure 6 to Figure 8. The eco driving speed was 49-56kmph (30.62 mph to 35 mph). This is exceeding the city speed limit. That indicates current speed limit is not fulfilling Eco driving for motorcyclist.

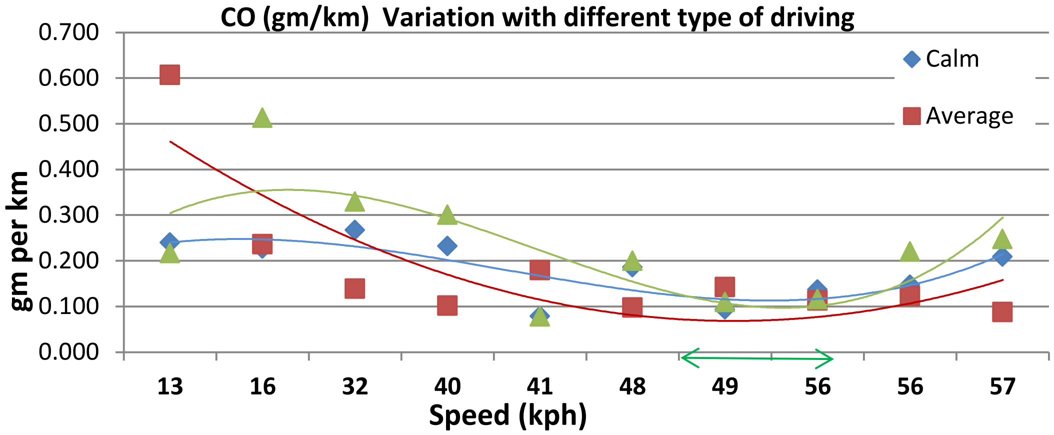

Figure 6. Impact of Driving Style on CO Emission

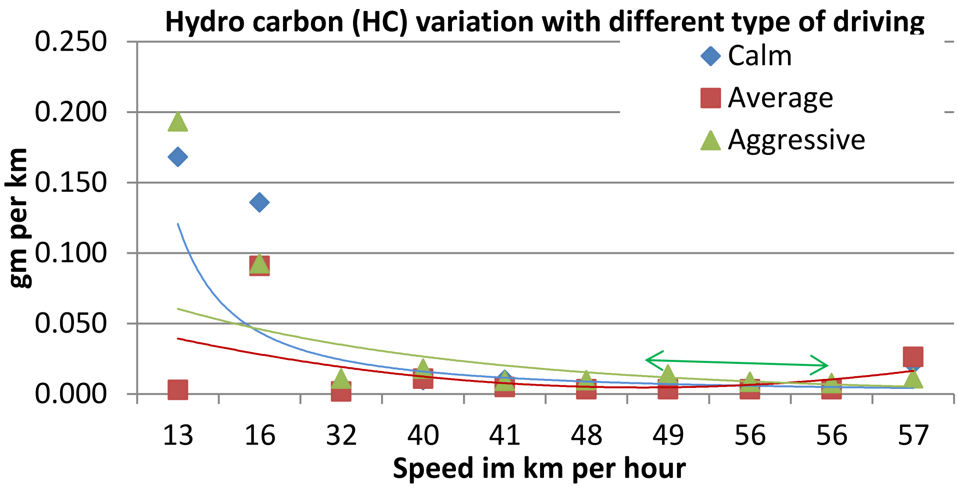

Figure 7. Impact of Driving Style on HC Emission

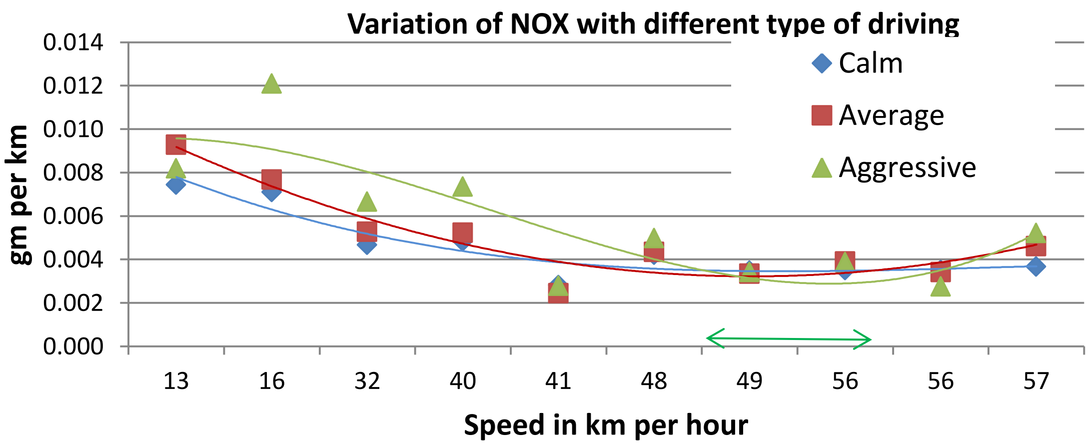

Figure 8. Impact of Driving Style on NOx Emission

Lower mean speeds produce higher CO_2 emission factors, while the influence on CO and HC is more complex. NO_X are not significantly affected by the driving pattern (Prati *et al.*, 2011). The variation also shows emission models which can represent the emission pattern in different driving pattern as follow.

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Table 5. Model Developed for Emission for Pollutant (CO, HC and Nox) for Different Driving Style

Pollutant	Type of driving		
	Calm	**Average**	**Aggressive**
Model for Carbon monoxide(CO)	$y = 0.0106x^2 - 0.1501x + 0.6006$ $R^2 = 0.7014$	$y = 0.0034x^3 - 0.05x^2 + 0.1754x + 0.1758$ $R^2 = 0.5718$	$y = 0.0014x^3 - 0.0199x^2 + 0.0564x + 0.202$ $R^2 = 0.6319$
Model for Hydrocarbon(HC)	$y=0.1206x^{-1.463}$ $R^2 = 0.6155$	$y = 0.0011x^2 - 0.0143x + 0.0525$ $R^2 = 0.1666$	$y=0.0795e^{-0.274x}$ $R^2 = 0.5595$
Model for Nitrogen Oxide(NOx)	$y= 0.0002x^2 - 0.0023x + 0.0113$ $R^2 = 0.8921$	$y = 4E\text{-}05x^3 - 0.0005x^2 + 0.0007x + 0.0093$ $R^2 = 0.7141$	$y = -8E\text{-}06x^3 + 0.0002x^2 - 0.0021x + 0.0097$ $R^2 = 0.8756$
Fuel consumption	$y = 0.0071x + 0.2668$ $R^2 = 0.9572$ Steady state		

Due to limitation of fuel measurement there was no instantaneous fuel measurement however there was measurement at steady speed as shown in Figure 9. This shows that as speed increases there is increase in fuel consumption as well. However there is need to explore more on this aspect using latest sensor available for carburettor based vehicle.

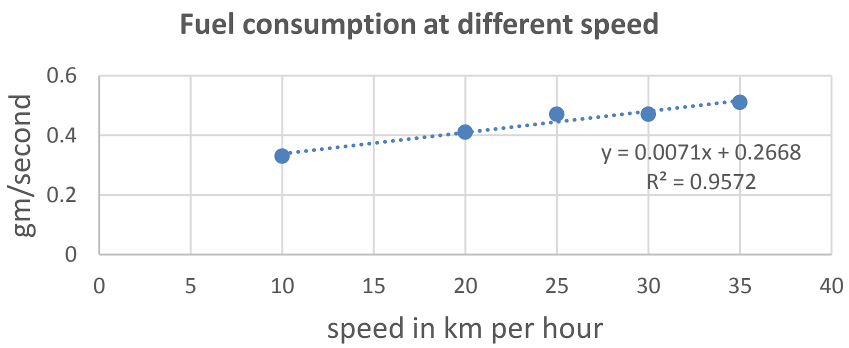

Figure 9. Impact of Steady State Driving Style on Fuel Consumption

4. Conclusions and Recommendations

Understanding the aggressive driving for motorcyclist in context with fuel consumption and emission are highly complex. Definitions of driving pattern cover from calm, normal to aggressive style among which aggressive driving behaviour has negative impacts on the environment due to higher production of emission. The results in this study confirms optimal saving of fuel and emission between driving speed of n49 to 56 kmph. Higher frequency of acceleration during aggressive driving should be reduced where as less aggressive drivers should focus on driving at lower speeds in cities. Driving behaviour is without doubt very important when calculating emission factors and more studies are needed in order to understand how the emissions vary depending on the speed, accelerations and decelerations. Developed emission model is able to predict produced emission under different driving styles. Model is statistically significant also which can be further developed for providing better transport and emission policies for motorcyclist.

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Reference

[1] I. Michelle Berry, "The Effects of Driving Style and Vehicle Performance on the Real-World Fuel Consumption of U.S. Light-Duty Vehicles", Master's Thesis, Massachusetts Institute of Technology, **(2010)**.
[2] Boulter, "Emission factors 2009: Report 3 exhaust emission factors for road vehicles in the United Kingdom, Department for Transport, **(2009)**.
[3] K. Chen, "Motorcycle emissions and fuel consumption in urban and rural driving conditions", The science of the total environment, **(2003)**, pp. 113-122.
[4] J. Gonder, M. Earleywine and W. Sparks, Analyzing Vehicle Fuel Saving, **(2012)**.
[5] Opportunities through Intelligent Driver Feedback. SAE Int. J. Passeng. Cars - Electron. Electr. Syst., vol. 5, no. 2.
[6] W.-T. Hung, H.-Y. Tong and C.-S. Cheung, "A Modal Approach to Vehicular Emissions and Fuel Consumption Model Development", Journal of the Air & Waste Management Association, vol. 55, no. 10, **(2005)**, pp. 1431-1440.
[7] E. R. Jayaratne, Z. D. Ristovski, L. Morawska, N. K. Meyer and C. Meyer, "Carbon dioxide emissions from diesel and compressed natural gas buses during acceleration", Transportation Research Part D: Transport and Environment, vol. 15, no. 5, **(2010)**, pp. 247-253.
[8] J. A. Joyner, "Factors Affecting Fuel Economy in Diesel Powered Vehicles", SAE Technical Paper 650430 (Cummins Engine Co., Inc.), **(1965)**.
[9] R. Kumar, "Modelling motorcycle driving cycles and emissions in Edinburgh", Phd Thesis, Edinburgh Napier University, UK, **(2009)**.
[10] M. V. Prati, "Influence of driving cycles on EURO 3 scooter emissions and fuel consumption", Energy Conversion and management, **(2011)**, pp. 3327-3336.
[11] S. Wafaa and K. Ravindra, "Sustainable Transportation Development: Behavioural And Emission Modelling", [Onlin]e http://iatbr2009.asu.edu/ocs/custom/resource/W1_R2_Sustainable%20Transportation%20Development%20Behavioral%20and%20Emission%20Modelling.pdf > [Accessed on 22 October 2013]
[12] S. K. Singh, "Review of urban transportation in India", Journal of Public Transportation, vol. 8, no. 1, **(2005)**, pp. 139-234.
[13] J. Seth Stichter, "Investigation of vehicle and driver aggressivity and relation to fuel economy testing", Master Thesis, University of Iowa, **(2012)**.
[14] T. H. Y. Tong, W. T. Hung and C. S. Cheung, "On-Road Motor Vehicle Emissions and Fuel Consumption in Urban Driving Conditions", Journal of the Air & Waste Management Association, vol. 50, no. 4, pp. 543-55.
[15] vJ.-H. Tsai, H.-L. Chiang, Y.-C. Hsu, H.-C. Weng and ChangYu Yang, "The speciation of volatile organic compounds (VOCs) from motorcycle engine exhaust at different driving modes", Atmospheric Environment, vol. 37, no. 18, **(2003)**, pp. 2485-2496.
[16] G.-H. Tzeng and J.-J. Chen, "Developing A Taipei motorcycle driving cycle for emissions and fuel economy", Transportation Research Part D: Transport and Environment, vol. 3, no. 1, **(1998)**, pp. 19-27.
[17] UNECE, Background paper, **(2004)**.
[18] Y. Zhang and J. Lv Wei Wang, "Evaluation of vehicle acceleration models for emission estimation at an intersection", Transportation Research Part D: Transport and Environment, vol. 18, **(2013)**, pp. 46-50.

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