Driving Cycle Pattern for Cars in Medium Sized City of India

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Abstract: The regulatory modified Indian driving cycle has uniform acceleration and deceleration pattern and uniform speed as it is adopted from European driving cycle. In medium sized city of Patna in India, the driving pattern changes substantially especially in absence of traffic signal and flat terrain. Also geometry of the city is such that cruising time for driver are more in vehicle operation. In this study seven routes have been selected which cater different land use patterns such as residential, commercial, education hubs, Industrial etc. Results show that average driving speed is 19.37 kmph with average idling of 20% in a trip. Results can be used to estimate real world fuel and emission and also value of travel time wasted during idling.

Keywords: driving cycle, cars, fuel emission, vehicle operating modes

1. INTRODUCTION

A driving cycle is a speed-time profile for a vehicle under a specified condition, usually selected to represent a glimpse of the real-life situation. Driving cycles have been known to provide a wide range of application for vehicle manufacturers, traffic engineers and environmentalists. The speed-time traces derived from the driving cycles can be used to estimate fuel consumption for a particular area (Kumar et al, 2013).

Driving cycles have been commonly classified into two broad types, namely [1] transient driving cycles, which are developed from on-road driving data, and [2] the 'modal' or 'polygonal' driving cycles, which compose of a sequence of steady-state modes. Examples of on-road data derived cycle are the US FTP cycle and Melbourne pack cycle. Japanese cycle and the ECE cycle are the representative example of 'polygonal' cycles. Previous research generally agrees that 'polygonal' cycles do not accurately characterize real driving behavior due to the fact that it statistically smoothes the effect of the vehicle modal operations (Tong and Hung, 2010). Relevant research in the past decades has been focused on the discussion of the first approach-development of transient driving cycles.

Transient driving cycles, based on on-road data, were derived under specific driving characteristics of a particular area of interest in Patna region of Eastern India [e.g. Major Arterial, Arterial and Sub Arterials]. These characteristics clearly differ from one area to another, even within the same city. As such, different methods have been used to derive driving cycles and a large number of driving cycle has thus been developed at different parts of the world.

In this paper driving cycle pattern of midsized city of Patna in Eastern India has been investigated and value of travel time wasted in idling of vehicle has been examined. The result shows that average speed of Patna driving for cars is 19.37 kmph.

1.1 Types Of Driving Cycles

1.1.1 Legislative and non-legislative driving cycles: Driving cycles can also be classified as legislative and non-legislative according to the way they are being used (Tunh and Hung, 2010). Legislative driving cycles are considered to be broadly representative of the driving conditions within their respective jurisdictions. They are provided to governments for motor vehicle emissions controls. The US 75 cycle, ECE cycle and Japan 10-15 mode cycles Indian Driving Cycle (IDC) are examples of legislative cycles being used to control vehicles emissions not only in their respective region but also in many developing countries that are without their own driving cycle.

Being more commonly used by researchers, non-legislative cycles are developed primarily for the estimation of exhaust emission and fuel consumption. The Sydney cycle, Improved European cycle (IEC), the Melbourne peak cycle and the Perth cycle are some of the examples. The IEC was developed for exhaust emission tests. The Sydney driving cycle was developed in the morning peak hours to estimate the emissions in this critical period. Since both types driving cycles are important for legislative and research purposes.

1.1.2 Existing driving cycle for cars in India: From the year 2000, India has adopted modified Indian Driving Cycle (IDC) for cars (same as ECE-15 +EUDC except maximum speed reduced to 90 km/hr). These driving cycles were developed to test the compliance of Indian vehicles to Indian emission standards and to quantify fuel economy. It has different operating conditions with fixed time interval. Base emission rates for most of the in-use vehicles are estimated using IDC (Ministry of Shipping, 2004). The characteristics of IDC are shown in Figure 1. Driving cycle is representative speed time sequence of vehicle of the area for particular vehicle. Development of representative driving cycles is an important part for setting up emission standard of vehicle and developing fuel efficient road network.

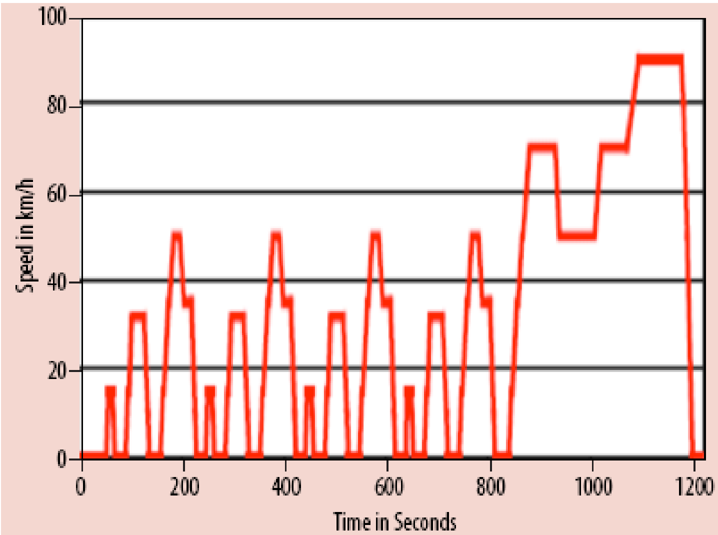

Figure 1: Modified Indian Driving Cycles for Cars

The New European Driving Cycle (NEDC) is a driving cycle consisting of four repeated ECE-15 driving cycles and an Extra-Urban driving cycle (EUDC). The NEDC is supposed to represent the typical usage of a car in Europe, and is used, among other things, to assess the emission levels of car engines. It is also referred to as Motor Vehicle Emissions Group (MVEG) cycle. Particular concerns arise because emissions testing with the NEDC under laboratory conditions might not represent the actual on-road emissions of light-duty vehicles with sufficient accuracy. Several studies have indicated that specifically on-road oxides of nitrogen (NOX) emissions of light-duty diesel vehicles might substantially exceed Euro 2-4 emission limits (Kumar et al., 2013, The Hindu, 2002).

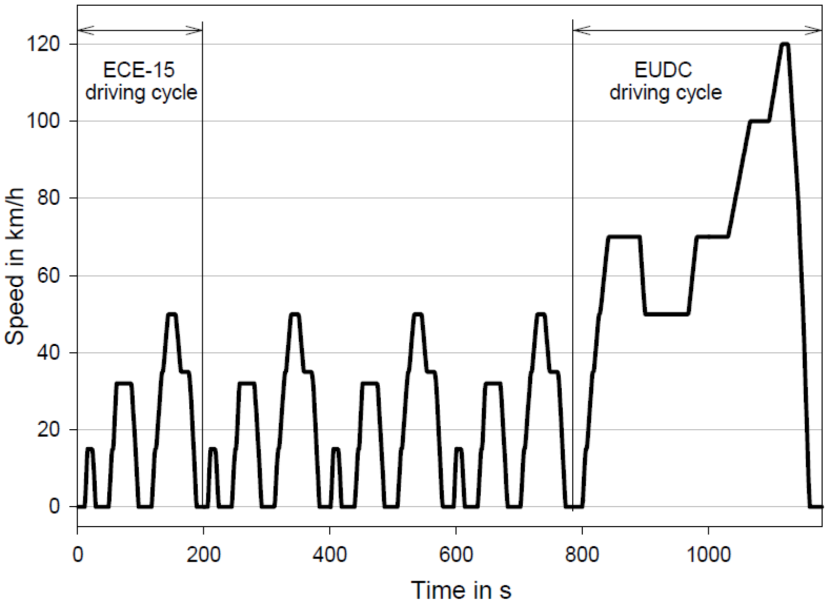

Figure 2: Speed profile New European driving cycle

The following are typical characteristics NEDC also modified as MIDC

- IDC assumes that all vehicle activities are the same irrespective of any variations in traffic and driving characteristics. This poorly represents the real-world driving patterns.
- IDC was developed under ordinary road conditions assuming that the grade is zero. however grade influences emission significantly. CO and NOX emission were twice as high in uphill (approx 4% grade) IDC does not differentiate between different classes of roads, where speed and acceleration frequency are different due to street design, traffic lights, congestion level that could influence emission rates.
- And well tuned vehicles are used for emission rate estimations as per IDC
- Current practice balances the operating conditions (acceleration, deceleration, idle, creeping and cruise) hence it cannot be used to analyze improvements due to traffic management schemes such as roundabouts, signal co-ordination, road widening etc.
- Current emission models uses standardized driving cycle (IDC), which neglects the speed and acceleration greater than 42 km/hr and $0.65 m/s^2$ respectively
- India has recently adopted modified Indian Driving Cycle for cars, though it considers speed and acceleration greater than 42 km/hr and $0.65 m/s^2$ respectively
- However, this also doesn't replicate the real-world driving, which is a serious concern (Nesamani, and Subramanian, 2005).

1.2 Need for the study

However, modified Indian driving cycle for car is in existence; its representations at local level control are still limited due to their uniform and steady driving cycle and lack of representation of local vehicle-based driving data. Many databases have been created on driving cycle for different types of vehicle by European Economic Commission (ECE) for European condition. The European Commission Directives (97/24/EC, 2002/51/EC) established common standards and procedures for evaluating motorcycle emissions 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 (EC Directive 2002/51/EC). COPERT 3 and 4 (Computer programme to calculate emissions from road transport) models are widely used to calculate both regulated and unregulated emissions of vehicle. The NEDC have been adopted for Indian condition (Ministry of Shipping, 2004, ARAI, 2007). However, all these driving cycles are based on fixed legislative driving standards of Europe, not on the local driving conditions (Saleh et al., 2009). Therefore this will not represent the true Indian condition, hence the result obtained from those driving cycles are not accurate and able to predict the solution for local conditions.

It should be mentioned here that many studies have been reported for Europe (e.g. France, Greece and UK) and Asia (e.g. Taiwan, Bangkok and Hong Kong) investigated the car and motorcycle driving cycle (Montazeri-Gh, M., Naghizadeh, M., 2000, Booth et al., 2001, Tung and Hung, 2010, Saleh et al., 2009, Kumar et al., 2011). Very limited studies have investigated driving cycle for Indian conditions. Only few studies have reported on car driving cycle for Delhi and Pune city (see Gandhi et al., 1980 and Kamble, et al.., 2009, Kumar et al., 2013). The study reported by Gandhi (1980), is very old. There is tremendous change in road, traffic and vehicular characteristics over the last 30 year. The study reported by Kamble et al 2009 is for Pune city and Kumar et al, 2013 for Delhi and NCR. The driving cycle developed for Pune city is not truly representative the driving cycle for New Delhi or Patna, due to differences in road, traffic composition and vehicular characteristics.

This study provides a platform for a large number of potential future applications for developing the driving cycle for minimising delays and congestion using different road network plan. Other studies undertaken on this subject as reported in the literature review for different country for example UK, Taiwan, Australia (e.g. Tung and Hung, 2010 Saleh et al., 2009, Hung et al., 2007; Kumar et al., 2010, 2011).

Numerous studies have been conducted to build up driving cycles in different contexts and demonstrate their strong influence on pollutant emissions (Covaciu, D., et al., 2010, Booth et al., 2001, Saleh et al. 2009, Kumar, 2010, 2011 and Hung, et. al., 2007). In Britain, the cost of an emission test on a single vehicle could be around £10,000 (Booth et al, 2001).Therefore, most often a unique set of driving cycles is used, independent of vehicle characteristics, which may be perceived as a weakness in terms of representation. In reality, the different types of vehicles are driven in different manners, and therefore they should be tested according to their performance levels and uses. Driving cycle is affected by many factors such as road geometry, traffic, time of traffic, speed limit, type of area (urban, suburban), and vehicle type. The driving cycle modelled for other city may not truly represent the driving cycle for mid size city Patna. Therefore, the city of Patna which is the capital of Eastern province of the state of Bihar of India has been chosen which has a population over 1.5 million.

2.0 EXPERIMENTAL METHODOLOGY

2.1 STUDY AREA.

Study area comprises of seven routes in Patna starting point from ITI railway colony Digha to NIT Patna, NIT Patna to Anisabad via Diadarganj, Anisabad to NIT Patna via Kankarbagh, Road , NIT to Khagual via Bailey Road, Saguna More as given in Figure 3. The selected road covers residential areas like Sheikhpura, Khajpura, Kankarbagh; commercial and business areas like Raja Bazar, Frazer Road, Ashok Rajpath, industrial area like Industrial Area on Didargunj to Anisabad section, and some free and high speed section on Didargunj to Ansiabad also NH 19, Saguna More to Khagaul etc.. The entire set of land use pattern has been covered in this section.

The traffic characteristics shows the composition as 24-28% two wheelers, 7-48% cars, 11-15% three wheelers, 5-28% buses and trucks and 4-34 % non-motorized vehicles. Composition domination was for cars, two wheel and three- wheelers in both directions. The route characteristics are summarized in Table 1. The surveys were conducted during peak hours in two subsequent days in month of February 2013 as presented in Table 2.

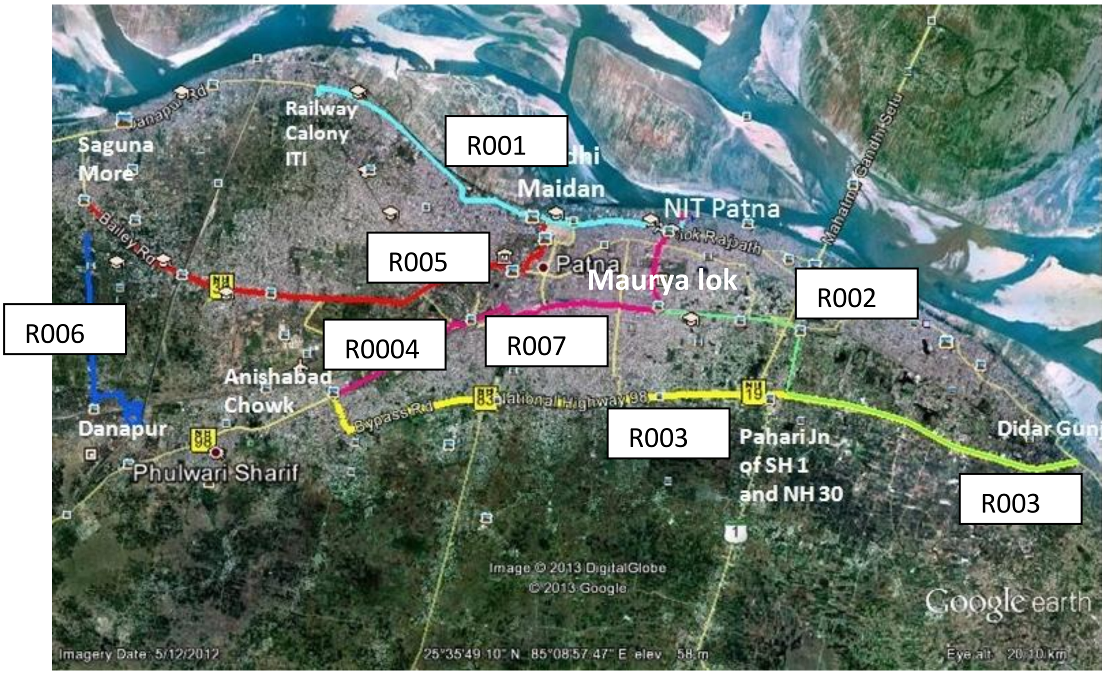

Figure 3: Study Area for driving cycle study and route maps (*Source: Google Earth, 2013*)

Table 1: Route Characteristics

Sr.No	Route Nomenclature	Route Code	Length (m)	Traffic (pcu)	Width	Lane
1	Railway Calony IIT Digha to NIT Patna via Rajapool, Gandhi Maidan	R001	9729	40003	8.5	2
2	NIT Patna to Didargunj via Pahari	R002	13850	48775	7.0	2
3	Didar Gunj Patna to Anishabad Chowk	R003	17321	23211	8.5	2
4	Anishabad Chowk to NIT Patna via Gardani bagh, Kankarbagh Patna	R004	10935	10000	14	4
5	NIT Patna to Saguna More via Baily Road	R005	15161	31371	14	4
6	Saguna More to	R006	6932	15600	7.5	2

	Danapur					
7	Mauryalok to NIT	R007	5455	71793	14	4

Table 2: Survey Schedule

Sl.No	Route Nomenclature	Route Code	Survey date	Start Time (hh:mm:ss.00)	End Time (hh:mm:ss.00)	Total Time (hh:mm:ss.00)
1	Railway Calony IIT Digha to NIT Patna via Rajapool, Gandhi Maidan	R001	04-02-2013	9:24:25.10	9:53:20.50	0:28:55.40
2	NIT Patna to Didargunj via Pahari	R002	04-02-2013	12:03:48.10	12:41:58.40	0:38:10.30
3	Didar Gunj Patna to Anishabad Chowk	R003	04-02-2013	12:42:33.7	13:20:31.00	0:37:58.36
4	Anishabad Chowk to NIT Patna via Gardani bagh, kankar bagh Patna	R004	04-02-2013	13:21:42.9	13:55:42.3	0:34:17.19
5	NIT Patna to Saguna More via Baily Road	R005	2013-02-05	12:49:14:10	13:43:19:10	00:54:05:00
6	Saguna More to Danapur	R006	2013-02-05	13:44:45:8	14:03:38:10	00:19:92:30
7	Mauryalok to NIT	R007	05-02-2013	15:07:55.3	15:28:44.7	00:20:49.19

2.2 DATA ACQUISITION AND INSTRUMENTATION

A vehicle of engine size of 1405 cc Bharat Stage III having mileage 10000 km was installed with the Performance box which is a high performance 10hz global positioning system (GPS), which means 10hz logging of time, distance, speed, position, g-force, lap times and split times as shown in Figure 4. This data was stored on a computer. Distance, speed, acceleration and time data were collected using a volunteer/owner on the given routes. Time-scale resolution of this data acquisition system was 0.1 seconds.

Figure 4: Performance box in running vehicle

Each day was covered by the morning peak (10 a.m. to 12 a.m.), afternoon peak (1:00 p.m. to 3:00 p.m.) periods, which takes account of daily variations. It is also expected that there would be differences in driving patterns due to the difference in activities at different periods.

2.3 DEVELOPMENT OF DRIVING CYCLE

Each second of the recorded data were assigned to one of the speed/acceleration intervals developed by Booth et al., (2001) to generate the necessary code. Hung et al. (2007) used 13 sets of relevant assessment parameter in the development of a car's driving cycle for the Hong Kong city and we also adopt these (Table 3).

Table 3: Selection of Assessment parameter to derive driving cycle

Sr. No	Driving cycle assessment Parameters	Symbol/ Unit
1	Average deceleration of all deceleration phases	d(m/sec^2)
2	Average acceleration of all acceleration phases	a(m/sec^2)
3	Average Speed of the entire driving cycle	V1 (Kmph)
4	Average Running Speed	V2(Kmph)
5	Mean length of driving period C(Seconds);	C(sec)
6	Time proportion of driving modes in idling(fraction of time spent at speed of 0-3Km/hr	Pi
7	Time proportion of driving modes in acceleration(a>0.9ms2)	Pa
8	Time proportion of driving modes in deceleration modes(d<0.1ms2)	Pd(m/sec2)
9	Time proportion of driving modes in cruising modes(a<=0.1ms^2,d<=0.1ms^2)	Pc
10	Average number of acceleration and deceleration changes within one driving period	M
11	Root Mean Square Acceleration	RMS
12	Positive Kinetic Energy(m/sec2)	PKE
13	Total driving length(M)	L(m)

Data coding and classifications were done using the methodology of deriving driving cycle by considering following equations (1 to 2).

$\acute{P}$ = Average of the average of the parameters of route 1 to 7 for week days.

$$= \sum \frac{(\text{�}\ r1\ to7pij)}{n} \quad (1)$$

Δ_i = Error in each parameter for week days.

$$= ((p_i - \acute{P})/\ p_i)*100 \quad (2)$$

Where,

$\sum\delta_i$: Sum of the errors of all the parameters for each trip in all routes of week days.

$r_{1\ to\ 7}$: Route 1 to 7

P_i : Driving cycle parameters obtained from the data collected (i= 1 to 13) from Table 3

$\acute{A}_{r1to7pij}$: Average of the parameters of route 1 to 7during week days.

Finally routes having minimum absolute error has been selected as candidate driving cycle.

3.0 DATA ANALYSIS

3.1 Determination of Parameters of Representative Driving Cycle of Patna

Above mentioned methodology in Section 2.3 was applied to determine the driving cycle parameter which is presented in Table 4 and Table 5.

3.2 Driving Pattern in Patna

From the data collected over different part of the city it is observed that average running speed was 23.47 kmph with standard deviation of 4kmph in the city. Average speed was 19.73 kmph with standard deviation of 3.95 kmph in the city. Cycle length (sec) was 2014(34 minutes) second standard deviation of 721 second (12 minute) kmph in the city. The time spent by vehicle in different operating modes was as follows:
It was observed that 14.59% time was spent in idling that counts 293.86 seconds (4.89 minutes/trips/vehicle). Vehicle spent 8.24% time in acceleration where as 10.67% time in deceleration activity. 66.52% time were spent in cruise activity.
Average Trip length in city was found to be 11km.

3.3 Driving Cycle of Patna

The representative driving cycle is shown in Figure 5. The driving cycle is totally different than modified Indian driving cycle adopted (Figure 1 & 2) as regulatory test purpose. Therefore Patna has different driving cycle which will result into different emission, fuel consumption. The derived driving cycle shows highest speed up to 50 kmph and idling due to stopping. Also many places cruising activity has been observed. From analysis absolute sum of error was observed for Route 004 which has been selected as candidate cycle.

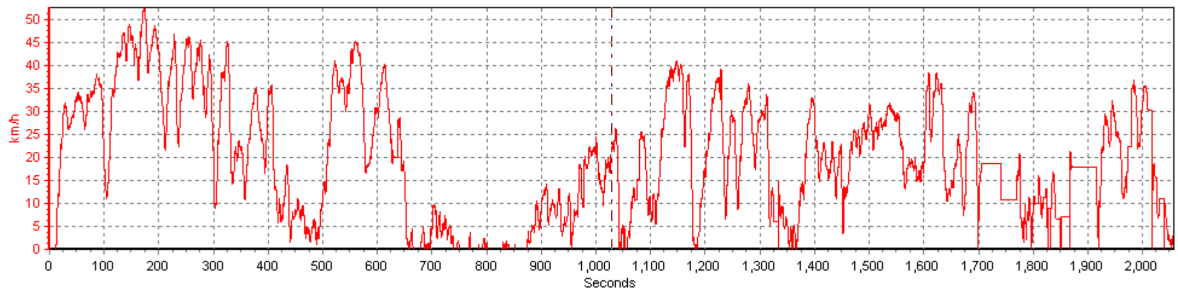

Figure 5 Driving cycle of Patna City

The driving cycle has average speed 17.81 kmph and running speed is 23.11 kmph with idling 22% (7.5 minutes per trip length per vehicle) along one trip. Their cycle length was found to be 38.28 minutes along with trip length of 10.17km. The typical driving cycle has 7% acceleration activity and 9 % deceleration activity that shows flat terrain condition of Patna and higher cruise 60% is attributed because there is hardly any signal in Patna. That shows that that stop and go operation are not frequent as compared to Delhi Roads (Table 6).

4.0 Conclusions

Patna's driving cycle is totally different to Indian driving cycle adopted as regulatory emission and fuel testing by Government of India. The speed of driving cycle is 17.18 Kmph with average idling time of 7.5 minutes. Interesting result was cruising activity of around 60% along the road that was due to not signal available along the city. The study concludes that medium size city should have their own driving cycle based actual data collected over the roads to have accurate emission and fuel consumption estimates. Once the representative driving cycle for any place is known, an estimate of emission can also be done using the speed-distance parameter of the cycle. Equations can be used to find out the emissions of carbon monoxide, hydrocarbon, and oxides of nitrogen, particulate matters, carbon-di-oxide and the consumption of fuel.

Table 4: Assessment of driving cycle parameters to derive candidate driving cycle for Patna

Date	Route	D (m/sec$^{2)}$	A (m/sec2)	V1 (Kmph)	V2 (Kmph)	C (sec)	Pi	Pa	Pd (m/sec2)	Pc	M	RMS	PKE	L(m)
4/2/2013	R001	-0.81	0.61	19.02	20.32	1806.20	6.14	10.95	13.01	69.90	2027.00	2.71	0.26	9543.06
4/2/2013	R002	-0.66	0.54	19.33	27.69	2329.40	28.46	6.07	8.45	57.02	3016.00	2.98	0.60	12505.08
4/2/2013	R003	-0.56	0.47	27.56	31.59	2267.90	11.99	5.55	8.30	74.16	3165.00	1.20	0.41	17361.95
4/2/2013	R004	-0.82	0.64	17.81	23.11	2057.30	22.01	6.86	9.31	61.81	2512.00	2.71	0.26	10179.28
5/2/2013	R005	-0.57	0.54	16.86	20.65	3259.70	17.60	7.25	9.44	65.71	4598.00	0.76	0.21	15265.85
5/2/2013	R006	-0.70	0.61	21.73	23.54	1133.90	6.96	10.41	13.20	69.43	1550.00	1.79	0.32	6845.05
5/2/2013	R007	-0.77	0.66	15.78	17.40	1244.50	8.96	10.57	12.88	67.59	1747.00	2.15	0.17	5454.27
	Average	-0.70	0.58	19.73	23.47	2014.13	14.59	8.24	10.66	66.52	2659.29	2.04	0.32	11022.08
	SD	0.109	0.068	3.95	4.806	721.97	8.414	2.32	2.26	5.663	1050.9	0.84	0.15	4315.64

Table 5: Estimation of Absolute Error observed in driving parameters for Patna

Date	Route	**D (m/sec^2)**	**A (m/sec2)**	**V1 (Kmph)**	**V2 (Kmph)**	**C (sec)**	**Pi**	**Pa**	**Pd (m/sec2)**	**Pc**	**M**	**RMS**	**PKE**	**L(m)**	**Absolute Sum of Error**
4/2/2013	R001	0.12	0.03	0.71	3.15	207.93	8.45	2.71	2.35	3.38	632.29	0.67	0.06	1479.02	2340.87
4/2/2013	R002	0.04	0.04	0.40	4.22	315.27	13.87	2.17	2.21	9.50	356.71	0.94	0.28	1483.00	2188.66
4/2/2013	R003	0.14	0.11	7.83	8.12	253.77	2.60	2.69	2.35	7.64	505.71	0.84	0.09	6339.88	7131.78
4/2/2013	R004	0.12	0.06	1.91	0.36	43.17	7.43	1.37	1.35	4.70	147.29	0.67	0.06	842.80	1051.29
5/2/2013	R005	0.13	0.05	2.87	2.82	1245.57	3.01	0.98	1.22	0.81	1938.71	1.29	0.11	4243.77	7441.34
5/2/2013	R006	0.00	0.03	2.01	0.06	880.23	7.63	2.17	2.55	2.91	1109.29	0.25	0.01	4177.03	6184.16
5/2/2013	R007	0.07	0.08	3.95	6.07	769.63	5.63	2.33	2.23	1.07	912.29	0.10	0.15	5567.80	7271.40

Table 6. Representative driving cycle in New Delhi for weekdays*

Date	Route	**D (m/sec$^{2)}$**	**A (m/sec2)**	**V1 (Kmph)**	**V2 (Kmph)**	**C (sec)**	**Pi**	**Pa**	**Pd (m/sec2)**	**Pc**	**M**	**RMS**	**PKE**	**L(m)**	**Absolute Sum of Error**
24/12/2012	Ali More to India Gate	-1.091	1.018	28.784	34.882	2649.296	6.009	42.294	40.075	9.202	6582.819	2.393	0.471	13311.91	2340.87

*Source: CRRI, 2012

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