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DRIVING CYCLE ESTIMATION AND VALIDATION FOR LUDHIANA CITY, INDIA

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Abstract: Traffic behavior of a city or any area can represent using driving cycle. In India, driving cycles were developed to test Indian vehicle emission standards but not considering higher speed and acceleration of vehicles. The assumption was all vehicle activities to be similar and considered traffic as homogeneous. But in India, traffic was heterogeneous each vehicle activity is different. In this study, the driving cycle was developed for estimating vehicular emissions and fuel consumption. Driving cycle is developed using five parameters namely percentage of acceleration, deceleration, idle, cruise and average speed of vehicles. Micro-trips were used to develop a driving cycle and these micro-trips are extracted from real-world data. K-means clustering method was used to cluster the micro-trips. The micro-trips which are nearest to the cluster centre represented as representative micro trips. These representative micro-trips are used for the development of the driving cycle. The driving cycles were developed and compared route and mode wise. The developed driving cycle was compared with Delhi driving cycle. It was observed that acceleration, deceleration rates were high compared to Delhi driving cycle. This methodology can be useful for heterogeneous traffic condition. The developed driving cycles can be easily identified the driving characteristics and vehicle emissions when testing on chassis dynamometers.

Keywords: fuel consumption, emission, micro trips, cruise, idle.

1. Introduction

The main sources of air pollution are vehicular emissions, industrial emissions, dust and storm, emissions from air craft and jets. Vehicular emissions are the main sources of atmospheric pollution in cities. Many cities are facing problems like traffic congestion, vehicular emission because of increase in vehicular population. According to national environmental engineering research institute, 60-70% of air pollution is caused because of vehicular emissions in all major cities. The factors mainly affecting the vehicular emissions are road characteristics and vehicular characteristics. Vehicular emissions are depending mainly on type of engine, age of vehicle, type of fuel and driving cycle. Automotive Research Association of India (ARAI) developed Indian driving cycle (IDC) based on assumption that traffic is homogeneous but actually which is heterogeneous. In IDC, average speed and acceleration considered as 42 km/h

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and 0.65 m/s^2, but in many cities, the speed inside city is limited greater than 42 km/h. Generally, the driving pattern is varies from city to city and region to region. The driving cycles developed in certain region may not be suitable to other regions. Generally, driving cycle was defined as "speed-time profile for a vehicle driving under a specified condition for a given city or region". Fuel consumption and vehicular emissions are measured using driving cycles for a particular area.

Driving cycles were divided into two types: transient and polygonal driving cycles. Transient driving cycles were developed based on the on road driving data (Melbourne peak cycle and US FTP cycles). Transient driving cycles were developed to urban or rural areas based on specific driving characteristics. These characteristics differ from one area to another and also differ in same city. The polygonal driving cycles were developed by compose of a sequence of steady state modes like constant acceleration and speed driving modes (Japanese and ECE cycles). These cycles do not explain the real driving behavior due to the effect of vehicle modal operations.

According to their uses, driving cycles were classified into two types: legislative driving cycles and non legislative cycles (Tong *et al.,* 1999). In legislative driving cycles, the driving conditions within their respective boundaries were considered and these cycles were delivered to government for vehicle emission controls. Non legislative cycles were developed for the estimation of fuel consumption and vehicle emissions.

According to the qualitative descriptions driving cycles were divided into three categories: urban driving cycles, sub urban/ composite driving cycles and highway driving cycle. Urban driving cycles have lower average speed and higher acceleration rates. It was observed that, regular stop and go operations in urban areas with heavy traffic flows and many intersections. Composite driving cycles have slightly higher average speed than urban driving cycles but smaller acceleration rates. Highway driving cycles have higher average speed but smaller acceleration rates. It shows that, very less traffic flows and limited stops and minimum number of intersections.

In this study, transient driving cycle was used. This study explains the development of transient driving cycle using five parameters like percentage of acceleration, deceleration, idle, cruise and average speed of vehicles for heterogeneous traffic condition.

2. Literature Review

Kent *et al.* (1978) developed a driving cycle for Sydney to estimate exhaust emissions. Average speed, root mean square acceleration and percentage idle time were used for driving cycle development. Hung *et al.* (2005) developed a model to analyze the driving characteristics by using three step approach. In the first step, 10 driving parameters were selected and used in the model. In second step, speed acceleration probability matrix (SAPM) was derived to know the distributions of speed and acceleration. In the third step, driving cycles were developed using 10 driving parameters and SAPM. Hung *et al.* (2007) presented a methodology to develop a driving cycle to estimate the vehicle emissions. Speed data was collected using on board and chase car technique. For the construction of driving cycle, a lot of parameters were selected. The developed driving cycle estimation model was validated using performance value and speed acceleration probability distribution (SAPD).

Nutramon and Supachart (2009) and Tamsanya *et al.* (2009) developed a new method for construction of a driving cycle for Bangkok. Data was collected on few routes and these routes selected that the traffic on these routes represent the traffic conditions on entire Bangkok traffic. Various driving parameters were used in driving cycle construction and these parameters derived from actual traffic data. The driving cycle was constructed by connecting series of several real world micro trips obtained from real traffic data. Kamble *et al.* (2009) develop an urban driving cycle for estimating vehicular emissions and fuel consumption. Five parameters were considered to develop a driving cycle namely percentage of acceleration, deceleration, idle, cruise and average speed. The driving cycle was constructed by connecting series of several real world micro trips obtained from real traffic data. Saleh *et al.* (2009) developed an urban and rural driving cycle for Hong Kong for cars. 12 parameters were selected for constructing driving cycle for cars. The representative driving cycle was selected by calculating the absolute sums of the relative error (S_j). The driving cycle with minimum relative error is the representative driving cycle. Saleh *et al.* (2010) developed a driving cycle for Edinburgh and Delhi using same methodology.

Tong and Hung (2010) proposed a framework on development of driving cycle based on 101 transient driving cycles. In 101 driving cycles, Asian driving was the slowest one and European driving is the fastest and smoothest. Traffic activity patterns should be considered to determining the test routes. Speed data collection methods namely on-board measurement, chase car techniques or their hybrid were explained. Most of the researchers ignored the tendency of zero change in acceleration while constructing driving cycle. Application of succession probability was explained at second-by-second level.

In this study, driving cycle was developed for heterogeneous traffic condition using five parameters. The next sections describe the methodology and in the subsequent section generation of micro-trips were discussed.

3. Methodology

A methodology was proposed for developing a real world driving cycle using micro trips and these micro trips represents the existing traffic conditions. The parameters were used to develop driving cycles are percentage of acceleration, percentage of deceleration, percentage of idle, percentage cruise and average speed. The methodology consists of driving data collection, micro-trips generation, data analysis and driving cycle construction.

3.1 Driving Data

Ludhiana city, in India was selected for this study. Ludhiana city is an important urban center in Punjab and a rapidly growing metropolis of the country. The selected routes and distances are tabulated in Table 1. On-board measurement technique was used to collect the speed-time data. This technique was used for large scale studies and data was collected directly and more accurately. Trimble GPS instrument was used for data collection. The instrument having high sensitivity GPS receiver with a field computer powered by the windows mobile version 6.1 operating system. The final data collection schedule was tabulated in Table 2. There are 2 out of 7 days as weekends that gives the almost 28% of the total week. So this supports way of dividing it into three trips from weekends and 6 trips from weekdays.

Table 1
Selected Routes Represent Real Traffic Conditions

S. No	From	To	Distance (km)
1	Jalandhar bypass	Dhandhari	10.3
2	Samarla chowk	Bhai bala chowk	8.0
3	Bhai bala chowk	Thakkarwal	6.4
4	Gill chowk	Gill bypass road	4.5
Total			31

Table 2
Data Collection Schedule

Day type	Number of trips			Total
	Morning peak	Afternoon peak	Evening peak	
Weekdays	2	2	2	6
Weekends	1	1	1	3
Total	3	3	3	9

3.2. Generation of Micro-Trips

The speed-time profile is divided into smaller units called as micro-trips for driving cycle development. Micro trip is defined as "trip between two consecutive time points at which vehicle is stopped". In previous studies, micro-trips were developed by manual count. In this study, micro trips were developed using MATLAB. Each micro-trip includes five parameters like percentage acceleration, percentage deceleration, and percentage cruise, percentage idle and average speed which were used for driving cycle development.

3.3. Data Analysis

Data analysis was done in two parts. In the first part, base data was analyzed and micro-trips were constructed. Base data analysis involves the development of speed–acceleration frequency matrix and normalized speed–acceleration matrix. The frequency of occurrence of acceleration, deceleration, cruise and idle corresponding to a speed values represented in a matrix form is called speed-acceleration frequency matrix. Normalized speed acceleration matrix was obtained by dividing each cell by total time and divide by 100. Micro-trips were constructed using computer program. In the second part, micro-trips were clustered using K-means clustering algorithm.

The speed–acceleration frequency matrix (SAFD) of three- wheeler on GT road was shown in Fig. 1. The normalized speed–acceleration matrix from the base data (SAPD) was shown in Fig. 2. The sample micro trip for three-wheeler was shown in Fig. 3.

kmph	<-10	-10	-9	-8	-7	-6	-5	-4	-3	-2	-1	0	1	2	3	4	5	6	7	8	9	10	>10	total
0..5	374	18	34	38	30	30	56	46	56	50	54	413	70	54	58	34	38	40	16	16	20	16	210	1771
5..10	294	18	24	18	16	20	30	32	48	12	16	32	22	22	24	24	30	26	26	12	18	20	340	1124
10..15	390	26	30	30	10	30	30	34	28	16	28	20	34	10	4	14	18	8	12	26	8	14	378	1198
15..20	476	62	58	56	36	36	54	32	24	22	24	32	26	22	40	26	28	26	20	48	42	28	518	1736
20..25	470	52	74	44	34	60	40	56	26	16	32	40	18	14	34	32	28	44	26	38	58	50	714	2000
25..30	556	62	72	82	84	70	56	62	52	22	50	60	32	38	48	48	48	40	38	76	82	86	764	2528
30..35	556	138	138	122	78	92	48	50	50	36	40	58	56	20	100	104	92	116	96	142	170	172	720	3194
35..40	364	106	114	76	72	74	60	56	88	62	120	118	160	94	166	172	178	160	130	176	172	152	324	3194
40..45	32	30	18	20	20	36	22	30	72	46	102	126	140	96	98	82	90	70	34	38	28	24	52	1306
45..50	0	0	0	0	0	2	0	0	0	0	0	0	0	0	2	0	2	0	0	0	0	0	0	6
50..55	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
55..60	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
60 on war	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
total	3512	512	562	486	380	450	396	398	444	282	466	899	558	370	574	536	552	530	398	572	598	562	4020	18057

dec	7888
acc	9270
idle	413
cruise	486
total	18057

Fig. 1.
The Speed–Acceleration Frequency Matrix (SAFD) from Base Data for 3W (Sample)

kmph	<-10	-10	-9	-8	-7	-6	-5	-4	-3	-2	-1	0	1	2	3	4	5	6	7	8	9	10	>10	total
0..5	2.0645	0.1004	0.1786	0.2009	0.1674	0.1674	0.301	0.2567	0.3013	0.2678	0.3013	1.7186	0.391	0.279	0.312	0.1786	0.19	0.212	0.089	0.067	0.0781	0.089	1.149	9.0615
5..10	1.6293	0.1004	0.1339	0.1004	0.0893	0.1116	0.167	0.1786	0.2678	0.067	0.0893	0.1786	0.123	0.123	0.134	0.1339	0.167	0.1451	0.145	0.067	0.1004	0.112	1.875	6.2381
10..15	2.1873	0.1451	0.1897	0.1674	0.0558	0.1786	0.179	0.1786	0.1562	0.0893	0.1562	0.1116	0.201	0.056	0.022	0.0781	0.1	0.0446	0.067	0.145	0.0446	0.078	2.154	6.785
15..20	2.656	0.3459	0.3236	0.3125	0.2009	0.2009	0.301	0.1786	0.1339	0.1228	0.1339	0.1786	0.145	0.123	0.223	0.1451	0.156	0.1451	0.112	0.268	0.2343	0.156	2.89	9.6864
20..25	2.6225	0.2901	0.4129	0.2455	0.1897	0.3348	0.223	0.3125	0.1451	0.0893	0.1786	0.2232	0.1	0.078	0.19	0.1786	0.156	0.2455	0.145	0.212	0.3236	0.279	3.984	11.159
25..30	3.1023	0.3459	0.4017	0.4575	0.4687	0.3906	0.312	0.3459	0.2901	0.1228	0.279	0.3348	0.179	0.212	0.268	0.2678	0.268	0.2232	0.212	0.424	0.4575	0.48	4.263	14.106
30..35	3.1023	0.77	0.77	0.6807	0.4352	0.5133	0.268	0.279	0.279	0.2009	0.2232	0.3236	0.312	0.112	0.558	0.5803	0.513	0.6472	0.536	0.792	0.9486	0.96	4.017	17.822
35..40	2.031	0.5915	0.6361	0.4241	0.4017	0.4129	0.335	0.3125	0.491	0.3459	0.6696	0.6584	0.893	0.524	0.926	0.9597	0.993	0.8928	0.725	0.982	0.9597	0.848	1.808	17.822
40..45	0.1786	0.1674	0.1004	0.1116	0.1116	0.2009	0.123	0.1674	0.4017	0.2567	0.5691	0.703	0.781	0.536	0.547	0.4575	0.502	0.3906	0.19	0.212	0.1562	0.134	0.29	7.2871
45..50	0	0	0	0	0	0.0112	0	0	0	0	0	0	0	0	0.011	0	0.011	0	0	0	0	0	0	0.0335
50..55	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
55..60	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
60 on war	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
total	19.574	2.8568	3.147	2.7006	2.1203	2.522	2.21	2.2096	2.4662	1.5623	2.6002	4.4303	3.125	2.042	3.192	2.9796	3.058	2.9461	2.221	3.169	3.3032	3.136	22.43	100

dec	43.968
acc	51.601
idle	1.7186
cruise	2.7118
total t	100

Fig. 2.
The Normalized Speed–Acceleration Matrix (SAPD) from the Base Data for 3W (Sample)

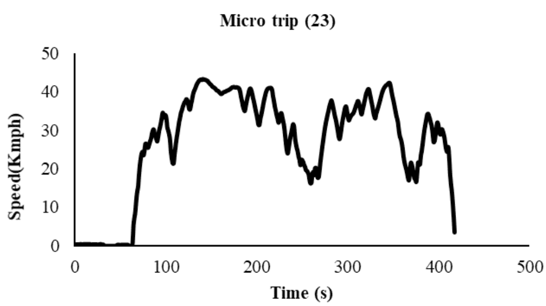

Fig. 3.
Micro Trip (23) for Three-Wheeler

3.4. Construction of Driving Cycle

Representative micro-trips were determined for each cluster for driving cycle development. The micro-trips nearer to cluster centers were selected as representative micro-trips and this process was to select enough micro-trips from all clusters to develop candidate driving cycle.

Performance value (PV) and sum squared difference (SSD) were used to select best driving cycle from all the candidate driving cycles. Performance value is the absolute sum of the difference between candidate cycle and target value. If the PV value is less, the real world driving pattern was represented more accurately. The candidate cycle with smallest PV value will be selected as the most representative driving cycle for the corresponding group. The PV value is given in Eq (1):

$$PV = |\theta_i - \theta_T|.W_T \quad (1)$$

Where, W_T is the transpose of the row weight vector corresponding to the set of statistics. θ_i and θ_T represents the five target parameters corresponding to the base data and candidate driving cycle. The weights assigned to five parameters were considered to be equal weight age because of the unavailability of the weights.

Mathematically SSD is given in Eq. (2). The candidate driving cycle with smallest SSD value is selected as representative driving cycle for the corresponding group.

$$SSD = \sum_{i=1}^{N_S} \sum_{j=1}^{N_a} (p_{ij} - q_{ij})^2 \quad (2)$$

Where N_s is the speed classes, N_a is the number of acceleration classes, p_{ij} is the ijth entry of the candidate cycle , and q_{ij} is the ijth entry of SAPD of the overall driving speed profiles. It is the sum of the squared differences of the corresponding cells of the base SAPD and candidate driving cycles SAPD.

4. Evaluation of the Driving Cycle

The developed driving cycle was compared with existing driving cycle and tabulated in Table 3. The comparison was done based on key parameters like percentage of acceleration, percentage of deceleration, percentage of idle, percentage of cruise and average speed. It was observed that, the percentage acceleration and percentage deceleration were high for developed driving cycle compared to other driving cycles. It means that, vehicle release more emissions and more pollution occurred if accelerations and decelerations were more. The average speed was observed to be more compared to others except Japanese and US driving cycles. The percentage of cruise and idle were observed to be less compared to others.

Table 3

Comparison of Driving Cycle Parameters from Ludhiana to other Studies

Driving Cycle Type	Speed	Cruise	Idle	Acceleration	Deceleration
ECE	18.35	29.23	30.7	21.54	18.46
Japanese	25.61	20.88	31.65	26.15	21.32
US 75	34.1	20.4	18	33.1	28.5
BDC	17.7	23.8	37.7	15.3	23.2
IDC	21.9	10.43	16.52	38.89	34.26
Pune	19.55	56.25	18.09	14.18	11.48
Present Study	24.83	2.392	5.404	50.997	41.174

5. Conclusions

Driving cycle was developed for measuring the fuel emissions and consumptions. The driving cycle's were constructed mode wise and route wise and compared. The parameters like the percentage acceleration, percentage deceleration, idle, cruise and the average speed were used for developing the driving cycle. Driving cycle was constructed based on micro-trips and these micro-trips were obtained by dividing the base data. K-means clustering technique was used to group the micro-trips based on similarity. SAPD and SAPD matrixes were constructed and these were used for dividing the whole data into speed-acceleration ranges form. Based on PV and SSD representative driving cycle was selected from all candidate driving cycles. For all modes, (car, three-wheeler, and two-wheeler) time spent in acceleration and deceleration in Gill road is less compared to other driving cycles. For all routes, GT road, NH 95, Pakhwoal road, and Gill road time spent in acceleration and deceleration were high for two wheelers compared to other driving cycles. The developed driving cycle was compared with other driving cycles. Time spent in acceleration and deceleration modes for Ludhiana driving cycles are found to be significantly higher than Delhi driving cycles and also all other driving cycles.

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