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REAL-WORLD DRIVING CYCLE IN HETEROGENEOUS TRAFFIC CONDITIONS IN DELHI FOR SUSTAINABLE TRANSPORT SYSTEMS

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Abstract: *Purpose* - The purpose of this paper is to improve the understanding of driving conditions in India that are heterogeneous in nature.

Design/methodology/approach - The driving cycle data were collected using GPS on different types of both motorised and non-motorised modes of transport, e.g. car, auto rickshaw, bus, motorcycle and cycle rickshaw and bicycle on different traffic corridors in Delhi.

Findings - Research findings show that driving cycles differ for different types of vehicles. Therefore, each mode should be encouraged based on their average speed-time sequence in any traffic mix. The real-world driving cycle will be also useful for the understanding of fuel consumption and emissions in real-world scenarios in order to control vehicle emissions properly, achieve fuel efficiency and to obtain a more sustainable transport system.

Originality/value - This type of research has not been carried out in any Indian city.

Keywords: *Driving cycle, Emission, Fuel consumption, Heterogeneous, Mixed traffic*

Paper type Research paper

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INTRODUCTION

Research into the driving cycles of different vehicles under different road traffic conditions is immensely useful for understanding fuel consumption, emissions, the planning and design of roadway systems and the operation of road traffic. Understanding real-world traffic behaviour regarding fuel consumption requires quantification of some of the basic vehicular driving characteristic in terms of time spent in different operating modes, speed and idling times. In general, emission and fuel consumptions factor estimates are not known accurately because emission factor prediction in India is based on the modified Indian driving cycle, which is developed based on the European driving cycle.

The driving cycle is expressed as the speed time sequence of vehicles for a region and city and is road- and driver-specific. Therefore, the European driving cycle, which is under highly homogeneous traffic conditions, wherein the difference in individual vehicle speeds and vehicle dimensions are negligible, cannot be adopted in India. In practice, however, even under homogeneous traffic conditions, there are significant differences in the said two characteristics (speed and acceleration) of vehicles. The measurement of driving cycles in European conditions hence becomes inapplicable for conditions with variations in the speed and acceleration of vehicles in the traffic stream. Therefore, the driving cycle measure needs to be redefined in order to make it appropriate for traffic conditions with significant variations in the vehicle type, road geometry and speed limit of vehicles in traffic streams.

The road traffic in countries like India is highly heterogeneous, comprising vehicles of wide-ranging static and dynamic characteristics. In addition, it is usual to establish emission factors on city-specific driving cycles, as there is continuous change in the road traffic pattern such as synchronization of traffic signals, lane upgradations, construction of flyovers, one-way traffic, restriction of entries of HCV in city areas and continuous increases in the density and technology of vehicles. Due to the widely varying vehicular type and speeds, the driving cycle measure, as applicable in Europe, is inappropriate for measuring vehicle driving cycles in roads carrying heterogeneous traffic. Here, the aim is to develop an appropriate driving cycle to represent traffic with potential for application to heterogeneous traffic conditions such as those prevailing on Indian roads.

EARLIER STUDIES

The Automotive Research Association of India (ARAI), along with the oil industry, developed a total of 62 emission factors depending on vehicle categories, vintages and engine cubic capacities out of the total 89 numbers of vehicles tested under the project for 450 numbers of emission tests. The emission factors (EF) reported by ARAI were based on prevailing driving cycles and a modified version of the EU driving cycle (ARAI, 2007). The driving pattern of one city or country may not be same as that for others for the reasons mentioned above. Use of the modified EU driving cycle will lead to EF that do not match a real-world scenario. Therefore, it is necessary to understand city-specific driving cycles and evolve emissions in the same way. As types of vehicle in Indian are expanding at a very rapid rate as more vehicle models are introduced, there is a need to evolve the emission factors on a continuous basis and on city-specific driving cycles, so that the information on emission factors is continuously upgraded to reflect the dynamic nature of the emissions scenario on account of continuous changes in the transport sector and traffic patterns of the city (ARAI, 2007; Saleh *et al.*, 2009; Kumar *et al.*, 2011, 2012).

EXPERIMENTAL METHODOLOGY

Study area

The study area comprises north, south, east and west Delhi, covering different roads as shown in Figure 6 and Tables 1 and 2. Table 1 shows the traffic flow on different roads in Delhi. For 12 hour traffic volume, the count ranges from 84,000 to 155,000 vehicles for 12 hours on different roads during week days, whereas the count was in the range of 57,000–131,000 vehicles in 12 hours for weekends. This shows that there is 15%–30 difference in weekend traffic volume. Road width varied from 25–45 meters. The selected roads cover the entire set of land use pattern in this study area. The traffic composition characteristics are as follows: 29% two-wheeled vehicles, 48% cars, 15% auto rickshaws, 4% buses and the remainder comprise trucks, cycles and LCVs. This indicates that the major traffic composition domination consists of cars, two wheel vehicles and auto rickshaws in both directions.

The survey was conducted at different hours of the day, including the morning peak (8.00–9.30 a.m.), the afternoon peak (1.00–3.00 p.m.) and the evening peak (5.00–8.00 p.m.) periods, which takes account of

Road name	Road Width		Road no	Hours	Week day	Hours	Weekend
Nehru Place to I.I.T. Gate	40.17 meter	(UP)	1	12	50578	12	29587
I.I.T.Gate to Nehru Place	41 meter (2 meter median 41)	(DN)	1	12	94623	12	35210
		Total			145201		64797
Baderpur to Ashram	(11x2+ 6 meter median)	(UP)	2	12	38039	12	39591
		(DN)	2	12	46407	12	31107
Ashram to Badarrpur		Total			84446		70698
Ashram to Lagpat Nager	(11x2+6 meter median)	(UP)	3	12	94672	12	62671
Lagpat Nager to Ashram		(DN)	3	12	61016	12	68458
		Total			155688		131129
Moolchand to Khanpur	24.0 meter (11.23 meter 4 lane + 11.23 (4 lane)	(UP)	4	12	66612	12	34722
Khanpur to Moolchand	44.00 (median 12 meter) + 3.23 median+1 1meter (4 lane)	(DN)	4	12	43555	12	22987
		Total			110167		57709

Table 1. Road and traffic characteristics of Delhi city

daily variations. Differences in driving patterns due to the variation in activities at different periods are also expected.

DATA ACQUISITION AND INSTRUMENTATION

The following were installed with the performance box: a car with an engine size of 1405 cc Baharat stage III, having a mileage of 152496 km; a motorcycle with an engine size of 125 cc; an auto rickshaw with an engine size of 145cc; buses with engine type BG & 230 Cummins BS III, water-cooled, turbo-charged inter-cooled CNG Engine 5883 cc; and non-motorized vehicles such as cycles and cycle rickshaws The performance box was a high performance 10hz global positioning system (GPS), which entailed 10hz logging of time, distance, speed, position, g-force, lap times and split times, as shown in Figures 1–5. The data were stored on a computer. Distance, speed, acceleration and time data were

Table 2. Summary of routes in Delhi- First Phase

Sr. No.	Location Name	Date	Start Time	End Time	Total Time (minute)	Reason of Selection
1	Baderpur To India Gate	22-11-2010	11:00	12:53	113	NH 2 leading Boarder Haryana Boarder in South Delhi Covering Office to Residential trip
2	Baderpur To India Gate		3:47	5:30	103	
3	Alipur More To India Gate	23-11-2010	9:19	10:19	78	
4	Baderpur To India Gate		11:13	12:34	81	
5	Alipur More To India Gate		3:38	5:00	82	
6	Baderpur To India Gate	27-11-2010	9:20	10:25	65	
7	CRRI-Alipur-India Gate	29-11-2010	3:30	4:49	79	
8	CRRI –Ashram-Mayourvihar-1,2-D.N.D Flyover-N.F.C-Ishver Nagar –Back CRRI	25-11-2010	9:14	10:16	62	Covering Residential Area and Expressway and Noida area and part East Delhi
9	CRRI –Ashram-Mayourvihar-1,2-D.N.D Flyover-N.F.C-Ishver Nagar –Back CRRI		11:42	12:33	52	
10	CRRI –Ashram-Mayourvihar-1,2-D.N.D Flyover-N.F.C-Ishver Nagar –Back CRRI		4:08	5:04	56	
11	CRRI –Ashram-Mayourvihar-1,2-D.N.D Flyover-N.F.C-Ishver Nagar –Back CRRI	26-11-2010	12:58	2:07	66	
12	CRRI –Ashram-Mayourvihar-1,2-D.N.D Flyover-N.F.C-Ishver Nagar –Back CRRI		3:51	5:01	69	

Continue

Table 2. Summary of routes in Delhi- First Phase

Sr. No.	Location Name	Date	Start Time	End Time	Total Time (minute)	Reason of Selection
13	Mahrani Bagh to LPS Hauz Khas		10:39	11:15	35	Covering Educational Hub, IIT LPS, Ring Road, and Residential Auditorium
14	Maharani Bagh To LPS Houj Khas		12:25	1:33	68	
15	Maharani Bagh To LPS Houj Khas		2:07	3:03	56	
16	DND flyover	28-11-2010	12:39	1:26	47	
17	CRRI To CRRI		10:52	11:53	61	Covering Market area North Delhi
18	New Delhi To D.B.Gupta Road	30-11-2010	12:06	1:57	111	
19	New Delhi To D.B.Gupta Road	1/12/2010	9:48	11:12	84	
20	New Delhi To D.B.Gupta Road		11:58	1:35	95	
21	New Delhi To D.B.Gupta Road	2/12/2010	10:59	12:31	91	
22	New Delhi To D.B.Gupta Road		1:25	3:05	100	
23	Dr.Ambedkar Nagar To Pragati Maidan	3/12/2010	10:37	11:52	74	Newly Introduced BRT corridor in Delhi
24	Dr.Ambedkar Nagar to Pragati Maidan		3:00	4:33	93	
25	Dr.Ambedkar Nagar to Pragati Maidan	4/12/2010	10:40	11:44	64	
26	Dr.Ambedkar Nagar to Pragati Maidan		3:36	5:50	124	
27	M.B.Road to Pragati Maidan	5/12/2010	10:23	11:18	55	

Figure 1.
Installation of equipment in motorcycle

Figure 2.
Installation of equipment in passenger auto rickshaw

Figure 3.
Installation of equipment in cycle

Figure 4. Installation of equipment in cycle rickshaw

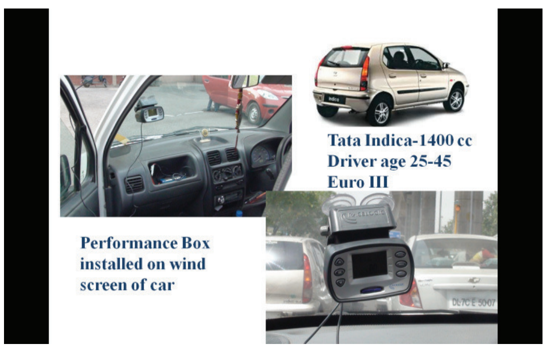

Figure 5. Installation of equipment in car

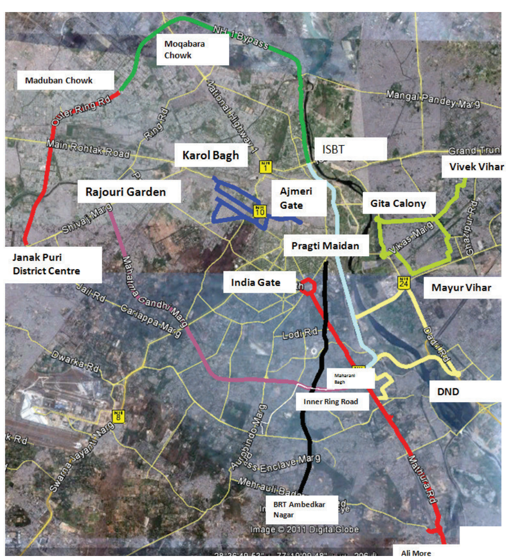

Figure 6. Study area map in Delhi

collected using a volunteer/owner on the given routes. The time-scale resolution of this data-acquisition system was 0.1 seconds.

DEVELOPMENT OF DRIVING CYCLE

Once data were collected, the whole data-set was processed using coding and classifications in order to derive the driving cycle by considering following equations (1 to 4):

□ = Average of the average of the parameters of route 1 and route 2 for week days.

$$= \frac{(Å\ r1piwj + Å\ r2piwj)}{2} \quad \text{(Eqn 1)}$$

$□_k$ = Average of the average of the parameters of route 1 and route 2 for weekend.

$$= \frac{(Å\ r1piwj + Å\ r2piwj)}{2} \quad \text{(Eqn 2)}$$

Δ_i = Error in each parameter for week days.

$$= ((p_i - □)/\ p_i)*100 \quad \text{(Eqn 3)}$$

Δ_k = Error in each parameter for weekend.

$$= ((pi - □_k)/\ p_i)*100 \quad \text{(Eqn 4)}$$

$\sum\delta_i$ = Sum of the errors of all the parameters for each trip in both routes of week days.
$\sum\delta_k$ = Sum of the errors of all the parameters for each trip in both routes of weekend.
R_1 = Route from Yamuna sports complex to Karkarduma. R_2 = route from Karkarduma to Yamuna sports complex.
W_j = Number of week days (j = 1 – 5).
W_k = Weekend (Sunday).
P_i = Driving cycle parameters obtained from the data collected (i = 1 – 12).
Å r1piwj = Average of the parameters of route 1 during weekend.
Å r2piwj = Average of the parameters of route 2 during weekend.
Å r1piwk = Average of the parameters of route 1 during weekend.
Å r2piwk = Average of the parameters of route 2 during weekend.

Finally, routes with minimum absolute error have been selected as the candidate driving cycle. Some typical driving cycles for different modes are shown in Figures 7–9.

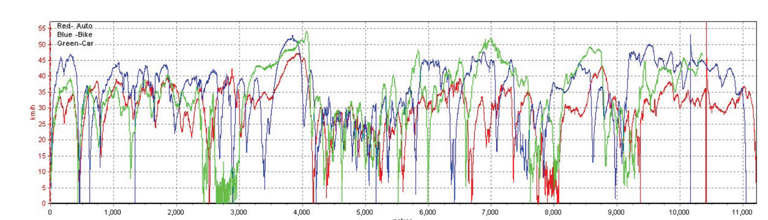

Figure 7. Typical driving cycle of car, motorcycle and auto rickshaw

Figures 7, 8 and 9 show that the auto rickshaw driving pattern is not the same as that of the car and motorcycle. The auto rickshaw always has limited speed in spite of being used as a private mode of transport. Engine size and driver behaviour influence the speed pattern. Buses have a typical driving pattern showing frequent stop and go at every bus stop. Their speed is also limited to 40 kmph. In contrast, car and motorcycle speeds go beyond 55 kmph. In spite of the speed limit of 50 kmph, drivers were not able to control their speed while coming down the side of the flyover. Surprisingly, cycles have fewer stop and go operations, while cycle rickshaws show a similar driving pattern, except their speed was found to be lower than that of cycles.

RESULTS AND DISCUSSION

Figures 10–24 show results obtained through analysis of data on different modes of transport.

Bus: Average driving speed was in the range 26.3–27.8 kmph. Average time spent in acceleration and deceleration was almost the same: 36–39%, idling was approximately 14%, which included bus stops and idling stoppages at intersections and in jam conditions. Their cycle length varied from 2 km to 12 km in terms of length. Times averaged at 2100 second (35.6 minutes).

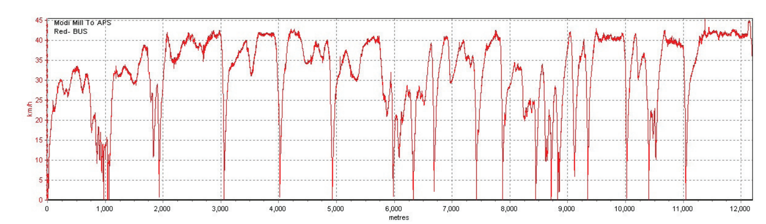

Figure 8. Typical driving cycle of bus

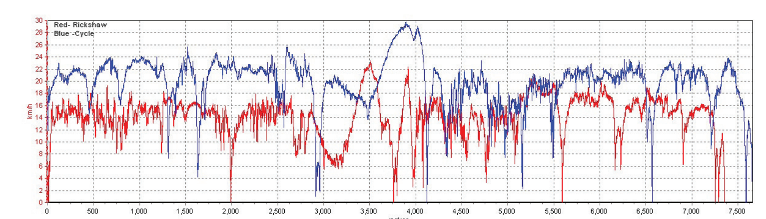

Figure 9. Typical driving cycle of cycle and cycle rickshaw

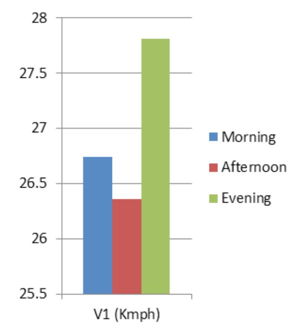

Figure 10. Speed of bus

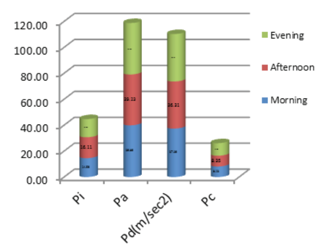

Figure 11. Time spent by bus in vehicle operating mode

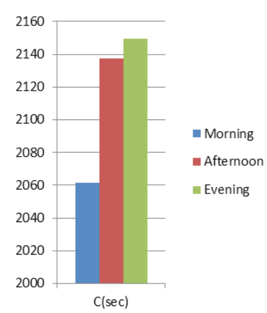

Figure 12. Cycle length (S) of bus

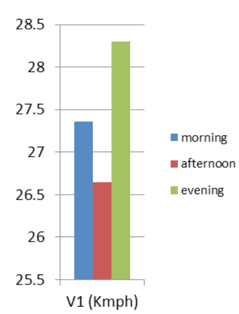

Figure 13. Speed of car

Car: Average speed was 28 kmph, which was higher than buses. Time spent in different vehicle operating modes was significantly different to buses. Time spent in acceleration and deceleration was 37–39%, cruising 9–10% and idling 13–14%, while their cycle time was 2400 second (40 minutes). Bus passengers have smaller trip times when compared to car passengers.

Motorcycle: Average speed was 30 kmph in the morning and 27.5 kmph at other times. Idling was less than modes of transport, at 3–4%. Cruising was 6–7%, while it was observed that more time was spent in acceleration and deceleration activity (46%). Cycle time was 1700 seconds (24 minutes), which was the shortest of all modes of transport existing on the roads. Two-wheeled vehicles are therefore popular in congested traffic environments.

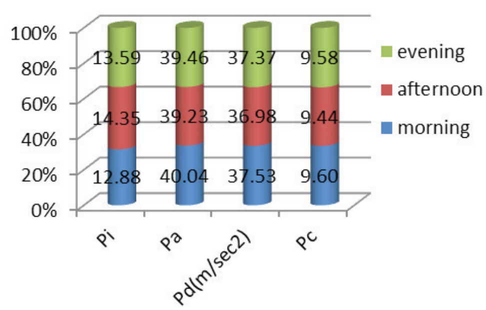

Figure 14. Time spent by car in vehicle operating mode

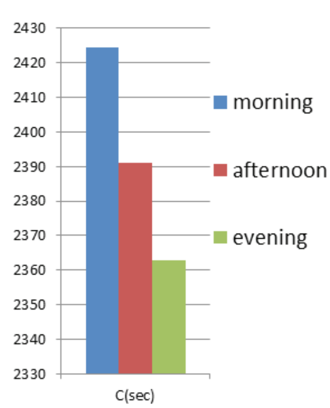

Figure 15. Cycle length (S) of car

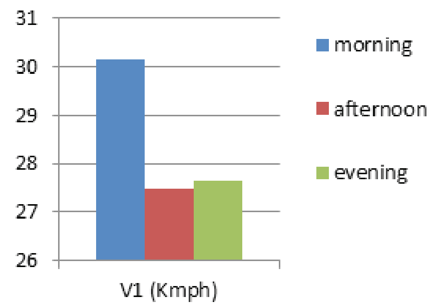

Figure 16. Speed of motorcycle

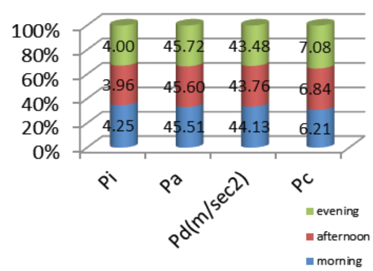

Figure 17. Time spent by motorcycle in vehicle operating mode

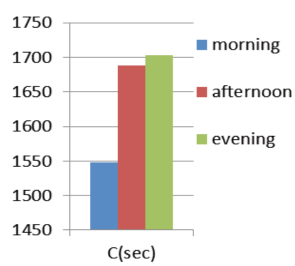

Figure 18. Cycle length (S) of motorcycle

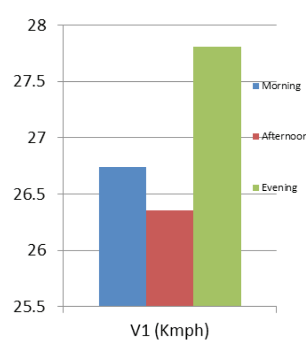

Figure 19. Speed of auto rickshaw

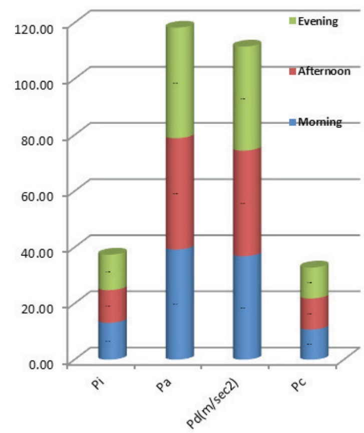

Figure 20. Time spent by auto rickshaw in vehicle operating mode

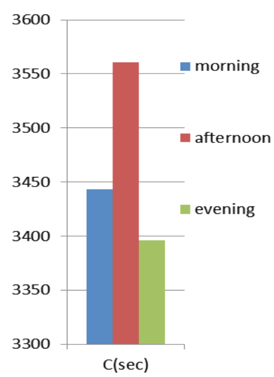

Figure 21. Cycle length (S) of auto rickshaw

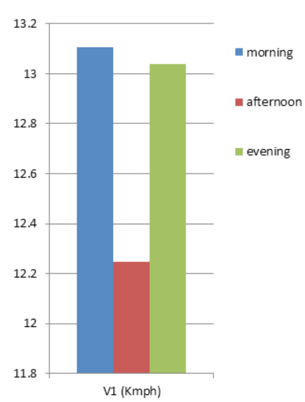

Figure 22. Speed of cycle

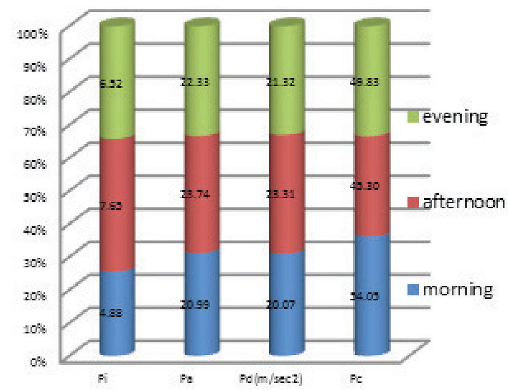

Figure 23. Time spent by cycle in vehicle operating mode

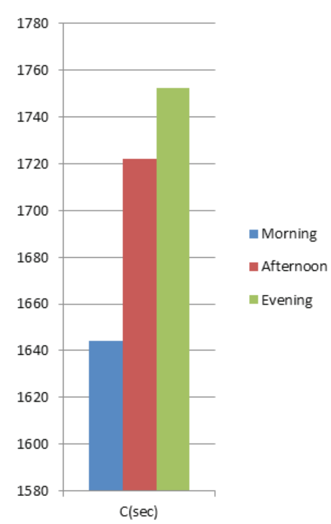

Figure 24. Cycle length (S) of cycle

Auto rickshaw: Average speed was 26–27 kmph, which was as fast as cars and motorcycles. However, their idling time was higher than cars and motorcycles at 11–13%. Their cycle length was 60 minutes. Auto rickshaws are normally used for longer trip lengths.

Cycle: Cycles are used for smaller trip lengths, therefore their cycle time was found to be less than that for auto rickshaws at 27 minutes. The important non-motorised operation had a higher time spent cruising (49–50%), as it is clear that acceleration and deceleration activities are minimised in manual transport. In addition, idling was 4–6%, which is similar to that of the motorcycle, but the average speed was 12–13 kmph, which is indicative of a limitation of the manual mode of transport.

CONCLUSION

Indian traffic compositions are heterogeneous in nature. Their driving patterns differ and result in variations in impedance and solutions to traffic problems. The driving speed of motorcycles was found to be higher than other modes of transport, whereas cyclists enjoy cruising and less idling time in spite of their lower average speed. The pattern of cycle rickshaw driving was found to be similar to that of cyclists, except for lower speeds. Buses have good average running speeds but a higher number of stop and go operations, hence higher idling time on journeys. In order to make the policy decision on corridor traffic management, it is important to know the driving pattern of different modes of transport, together with their journey speeds and delays. These parameters can be used to determine the performance of the corridor. Since the driving cycle also identifies the spot-location of congestion, it is highly useful in improving the traffic demand. The accurate estimation of driving cycles will provide realistic emission and fuel consumption patterns for different vehicle running times spent in different vehicle operating modes.

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