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Effect of Extreme Weather Conditions on Speed Profiles of Drivers: A Case Study in Delhi, India

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Abstract: ***Adverse weather conditions in India and temperature fluctuations are the major causes of an elevated risk of traffic accidents and traffic flow. In India heavy rain and foggy winters impair the road conditions; the effect of such conditions on driver behaviour has been a matter of concern for many years and the subject of Past research. Main focus of the present study was to understand how an individual driver responds to certain stimuli according to his/her individual characteristics during various driving conditions. The data acquisition of this study was done with V-box. Different driving cycles were also recorded during the data acquisition. The findings highlight drivers' state and pattern of crashes during rain and foggy conditions during simulated adverse weather conditions. From the data this has been observed It is clearly seen that average driving time differ by 120 seconds in rainy season on the same track i.e 4 % extra time in rainy season. Based on these findings this has been recommended that frequency and severity of accident like situations and other related incidents can be reduced by providing drivers with enough information about the roadway and traffic conditions as well as through better traffic management during adverse weather conditions. Advanced motorist warning systems about weather-related conditions can be proved better tool for understanding of driver's responses during adverse weather conditions.***
Keywords: Idling Time, V-box, driving cycles.

I. INTRODUCTION

Adverse weather in India poses serious hazard to roadway safety through increasing travel time, reducing speeds, increasing speed variance and decreasing roadway capacity. Every year manifold variations in weather can be seen in account of temperature, humidity level and rainfall and this resultant to the occurrence of climatic anomalies such as cold wave, fog, snow storms, avalanches, hailstorm, thunderstorm, dust storms, heat wave, tropical cyclones and tidal waves (De et al 2005). The effects of these variations are underestimated, especially due to underreported weather-related accidents, lack of research work and insufficient measures to handle the demanding driving conditions in adverse weather conditions. Transport demand and unsafe operation factors influence the rate and severity of road accidents, the former is related to traffic exposures i.e. volume and traffic characteristics, while the latter is concerning unsafe vehicle operations (Andrey et al 2001). Extreme weather such as heavy rain and fog poses severe threat in road safety in India. Due to low visibility sometimes fog related road traffic accidents involve multiple vehicles resulting in vehicle pile ups. These accidents are in general fatal or severe due to the fact that multiple vehicles are involved which makes escaping very hard. The risks in vehicle operation may be contributed by the deterioration in driving and vehicle performance as well as unfavourable road and environmental conditions. Adverse weather is one of the environmental factors that are known to affect the performance of a "moving vehicle", especially in the situations where road friction is reduced; visibility is poor and many other factors such as arterial mobility, poor traffic signal operations that impair driving performance and road safety (Andrey al al 2003).

Many researcher such as Kanelaidisetal.,1990; Fitzpatrick et al., 2003; Ali et al., 2007; Park et al., 2010; Eluru et al., 2013 have carried out investigation to determine the factors which influences influencing operating speeds and traffic volumes in rural and urban environments. But most of them have investigated the effects of geometric characteristics or speed limits, using cross-sectional data primarily. Donaher et al. (2012) developed two different linear regression models for the speeds on rural and urban highways in Ontario using parameters such as wind speed, visibility, snow, and temperature. They found that operating speeds are also quite sensitive to adverse weather. Usman et al., 2010 found a link between highway traffic (i.e. speed and volume) and surface conditions or winter maintenance operations which was also associated with safety and road condition highways.Few studies have investigated the potential lagged effects of adverse weather, in particular snow and/or rain precipitation on operating speeds and traffic volumes during wintertime. It is not surprising to observe reductions in the speed and the volume under adverse weather conditions. Ting Fu (2014) investigated the effects of Adverse Winter Weather Conditions on Highway Traffic and Driver Behaviours before and after a snow/precipitation event. If snow precipitation affects a given road section, speeds, as well as traffic volumes, are expected to be negatively affected not only during the event but also before and after the event. He also observed the impact of weather across different road types (urban versus rural highway) and day of week (weekdays versus weekends). For instance, note that urban commuters seem to suffer more from the adverse weather such as winter storms.Linear regression models are commonly used in modeling traffic characteristics (e.g., speed, traffic volume). However, time series models seem to be a better option (e.g., they allow one to consider correlation among time dependent error terms and lagged effects) in modeling traffic characteristics such as the traffic volume and the speed .Using time series, very limited number of studies considered climate conditions (Vlahogianni and Karlaftis, 2012). Ting Fu (2014) investigated the direct and lagged effects of adverse weather conditions during winter on the operating speed and the traffic volume using a time-series modeling approach to better understand speed and volume variations during, before, and after winter storms or other adverse weather conditions (extreme low temperatures and high wind speeds) for a large dataset containing hourly traffic data from different highway segments in Ontario, of weather variables (e.g., temperature, snow, wind speed), and

surface conditions . Similarly, Pipkin (1989) used this model to outline the ARIMA framework in modeling traffic flow series without considering weather variables in their analysis. However no study has explored the effect of weather on different vehicle operating condition and its impact on speed in urban condition of Delhi city. In this study, regression model, time-series regression techniques (ARIMA models) and derived pattern of driving along corridor in different weather condition is explored which also shows that effect of weather condition on average speed, acceleration deceleration cursing during different weather condition.

The gamut of these researches helped to create the background of the present case study in Delhi, India under different Indian weather conditions where it was felt to study the speed profiles and vehicle idling time for all weather conditions. In this study, regression model, time-series regression techniques (ARIMA models) and derived pattern of driving along corridor in different weather condition is explored which also shows that effect of weather condition on average speed, acceleration deceleration cursing during different weather condition in the capital of India.

II. OBJECTIVE

The main objective of this study was to examine the effect of adverse weather conditions (in the form of different weather condition such as clear day, rainy, cloudy day, foggy day) on the vehicle operating speed and operating conditions.

III. METHODOLOGY

Main focus of the present study was to understand how an individual driver responds to certain stimuli according to his/her individual characteristics during various adverse driving conditions.

A. Sample Size and Characteristics

Twenty one commercial vehicle drivers pertaining to the age group up to twenty to forty years with minimum two years to maximum fifteen years commercial driving from same economic background were randomly selected for the present study.

B. Procedure

Under field setting with the help of the V-Box driver's characteristic were measured. In which driver's reaction time, facial movements and road assets were measured with the help of three cameras of V-box during the various driving situations. Different driving cycles were also processed during the data acquisition.

IV. FINDINGS OF THE PRESENT STUDY

The operating speed on urban road is affected by different factors, e.g., weather conditions and traffic characteristics. Figure 1 illustrates how various factors affect the operating speed. In addition to the linear regression model, a time series approach in modeling the speed was adopted, which allowed the consideration of lagged effects as well. In particular, time series event-based modeling approach was employed to study the trend of speeds under different weather conditions.

Figure 1: Relationship between Speed Variables

A. Data Analysis of Candidate Driving Cycles

Derivation of representative driving pattern at different weather conditions**.** In the present study data was collected for 36 days during all weather conditions for two consecutive years i.e. 2012-2013, 2013-2014 by using V-Box, installing three cameras. The data was processed at the CSIR-CRRI laboratory for speed and driving pattern (cycle).

Findings of the data revealed that average driving time differ by 120 seconds in rainy season on the same track i.e 4 % extra time in rainy season. During Up and Down stretch the average speed on 2 lane, 3 lane and 4 lane was observed as 34.1kmph, 47.72 kmph and 63.25 kmph respectively for UP (CRRI-IDTR Loni and 39.14kmph, 54.61kmph and 62.42kmph (water

logging) for DOWN (IDTR-CRRI) stretches. Based on equation 1 to 5 the following Table 1 shows the results of speed differences for both years. The minimum of difference in speed chooses as the representative cycle for that weather condition. It is clear from the table that minimum value of speed differences for the year 2012 in different weather condition such as cloudy, clear, rainy and foggy were recorded as -3.42Km/hr, -13.07Km/hr, -4.48 Km/hr and -13.3Km/hr respectively. Similarly for the year 2013 in different weather condition such as cloudy, clear, rainy and foggy speed differences were recorded as -2.96 Km/hr, -2.50 Km/hr, -2.81 Km/hr and -7.9 Km/hr respectively.

Table 1: Difference in Speed to Find Out Candidate Cycle for Each Weather (2012)

Weather Day	Average Speed (km/hr.)	Difference in Speed (km/hr)					
	Speed	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6
Cloudy day	37.53	-0.12	3.5	-3.42			
Clear day	25.3	11.25	-4.58	6.44	6.44	-13.07	-6.18
Rainy day	36.25	-4.48	1.46	3.01			
Fog day	27.32	13.7	-6.99	-13.33	-7.1	-4.21	17.92

Table 2: Difference in Speed to Find Out Candidate Cycle for Each Weather (2013)

Weather Day	Average Speed(km/hr)	Difference in speed (km/hr)				
	Speed	Day 1	Day 2	Day 3	Day 4	Day 5
Cloudy day	31.27	2.75	-2.96	1.06	-0.85	
Clear day	21.08	-2.5	0.65	-0.53	2.4	
Rainy day	29.61	4.52	-2.81	-2.66	-0.7	1.65
Foggy day	24.97	-4.13	5.73	5.12	1.16	-7.9

Now based on speed criteria a comparison graph was plotted to know the driving pattern along the corridor in different weather conditions which is shown for UP & Down conditions for the year 2012 and 2013 as shown below in Figure No. 2 to 5. For all weather days and for both years driving Cycle graphs are enclosed in Annexure 1.

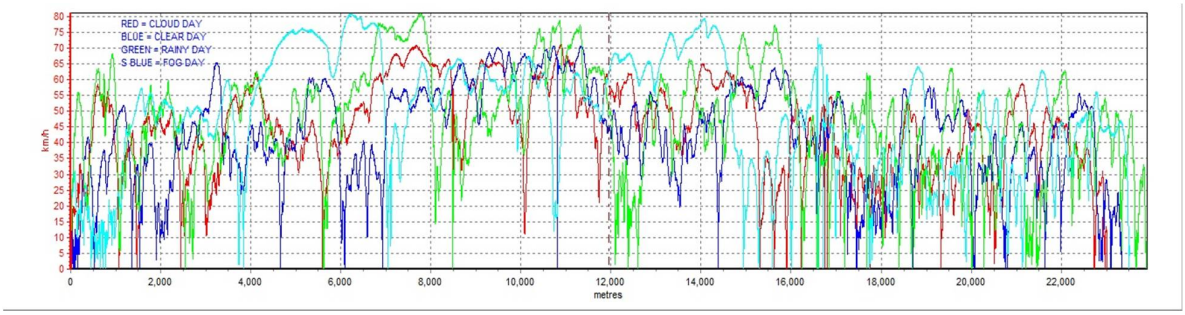

Figure 2: Comparative speed profiles (Year 2012) (UP direction)

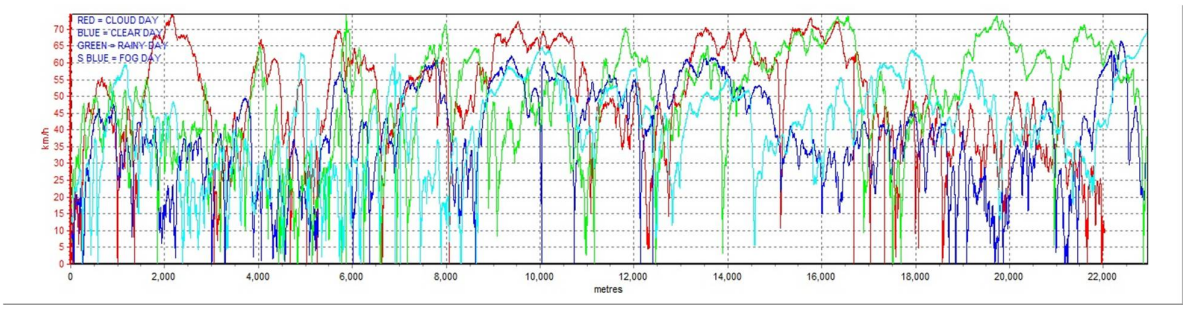

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Figure 3: Comparative speed profiles for the year 2012 (Down direction)

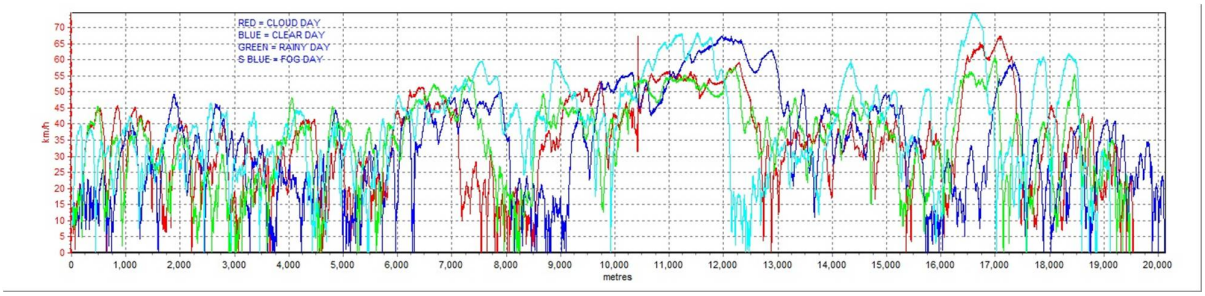

Figure 4: Comparative Speed Profiles (Year 2013) (UP direction)

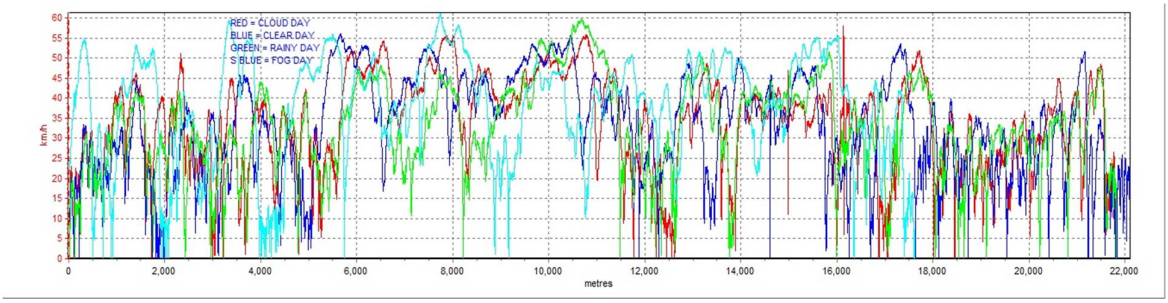

Figure 5: Comparative Speed Profiles (Year 2013) (Down direction)

From the figures 1 to 5 the comparative driving pattern under different weather conditions was observed having not much difference except rainy days.

B. Effect of Weather Condition on Different Vehicle Operating Modes

The computed percentage of time spent in idling, acceleration and deceleration with travel time and speed data for both the years have been shown below in tables 1&2. Percentage of time proportions for representative driving cycle for each weather conditions on the basis of speed variable are shown here in bold letters.

From the data this has been observed that the idling time of the vehicles was observed highest during rainy season. In year 2012 recorded idling time were 21.2% and in 2013 it was 10.37% percent (table- 3).

Table 3: Represents the Percentage Driving Time Proportion of Different Driving Modes for the Year-2012-13 * Representative sample

S. No.	Day	Travel time (Sec)	SPEED (Km/hr)	% Time spent in idling	% Time spent in acceleration	% Time spent in deceleration
CLOUDY DAY						
1	DAY 1	2963.3	37.65	24.88	38.87	36.25
2	DAY 2	2015.7	34	21.82	40.05	38.14
3	DAY 3	2754.6	40.95	18.10	42.24	39.66*
CLEAR DAY						
4	DAY 1	6038.8		34.90	33.13	31.97
5	DAY 2	2923.3	29.88	16.16	43.51	40.33
6	DAY 3	4529.6	18.86	27.10	37.46	35.43
7	DAY 4	4529.6	18.86	27.10	37.46	35.43
8	DAY 5	1927.3	38.37	18.99	42.16	38.86*

9	DAY 6	3340.9	31.48	7.18	40.16	38.55
RAINY DAY						
10	DAY 1	3083.8	40.73	21.20	41.58	37.22*
11	DAY 2	3067.8	34.79	18.35	42.34	39.32
12	DAY 3	2095.9	33.24	21.50	39.09	39.42
FOGGY DAY						
13	DAY 1	5814.6	13.62		35.55	34.85
14	DAY 2	3151.3	34.31	2.20	50.12	47.69
15	DAY 3	2288.3	40.65	2.08	50.32	47.61*
16	DAY 4	2577.2	34.42	2.34	49.95	47.72
17	DAY 5	2682.5	31.53	2.11	49.98	47.91
18	DAY 6	4056.4	9.4	27.14	36.88	35.98

Table 4: Represents the Percentage driving time proportion of different driving modes for theYear-2013-14

S. No.	DAY	TRAVEL TIME (Sec)	SPEED	% Time spent in idling	% Time spent in acceleration	% Time spent in deceleration
CLOUDY DAY						
1.00	DAY 1	3265.60	28.52	2.95	49.05	48.00
2.00	DAY 2	2873.50	34.23	2.35	49.17	48.48
3.00	DAY 3	2793.00	30.21	1.88	49.50	48.63
4.00	DAY 4	2760.10	32.12	1.68	49.45	48.88
CLEAR DAY						
5.00	Day 1	3003.20	23.58	1.15	49.93	48.93
6.00	DAY 2	2044.60	20.43	2.15	49.51	48.34
7.00	DAY 3	2767.10	21.61	3.05	50.03	46.93
8.00	DAY 4	3622.30	18.68	3.27	49.22	47.52
RAINY DAY						
9.00	DAY 1	2285.70	25.09	1.28	49.47	49.26
10.00	DAY 2	2294.70	32.42	10.37	45.61	44.03
11.00	DAY 3	982.40	32.27	4.96	46.95	48.11
12.00	DAY 4	2286.00	30.31	17.19	51.00	47.29
13.00	DAY 5	1356.40	27.96	1.77	50.77	47.46
FOGGY DAY						
14.00	DAY 1	2383.60	29.10	1.23	49.74	49.03
15.000	DAY 2	2357.50	19.24	1.35	50.44	48.21
16.000	DAY 3	2318.10	19.85	1.35	48.16	47.91
17.000	DAY 4	2846.00	23.81	2.93	51.62	47.56
18.000	DAY 5	2702.20	32.87	2.73	49.99	51.40

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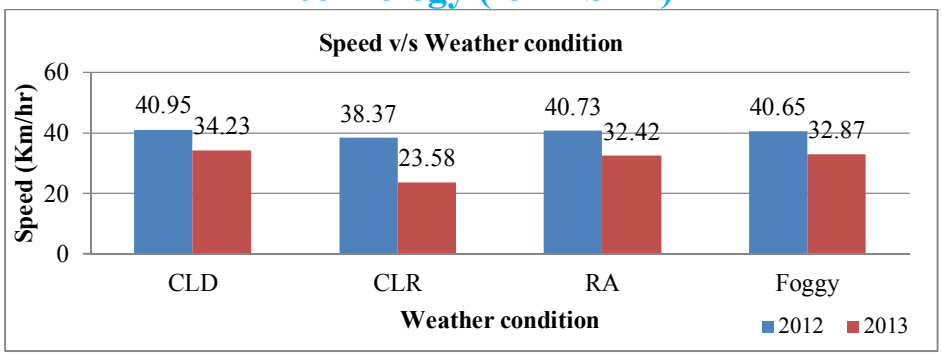

Figure 6: Speed Pattern during Different Weather Conditions
(CLD: Cloudy weather; CLR: Clear weather; RA: Rainy weather)

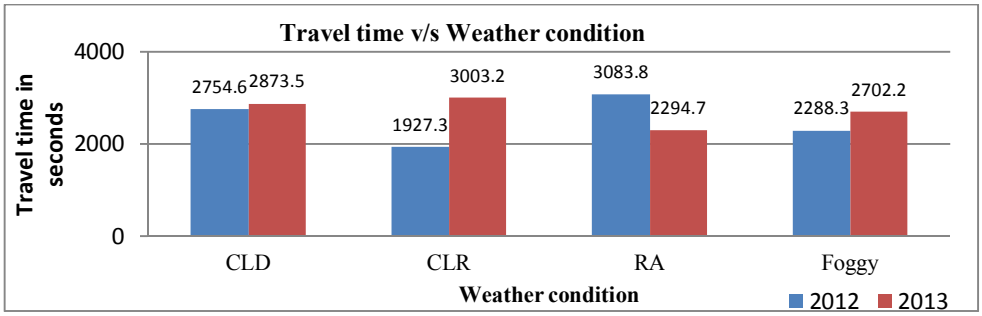

Figure 7: Travel time (secs.) along the corridor during different weather

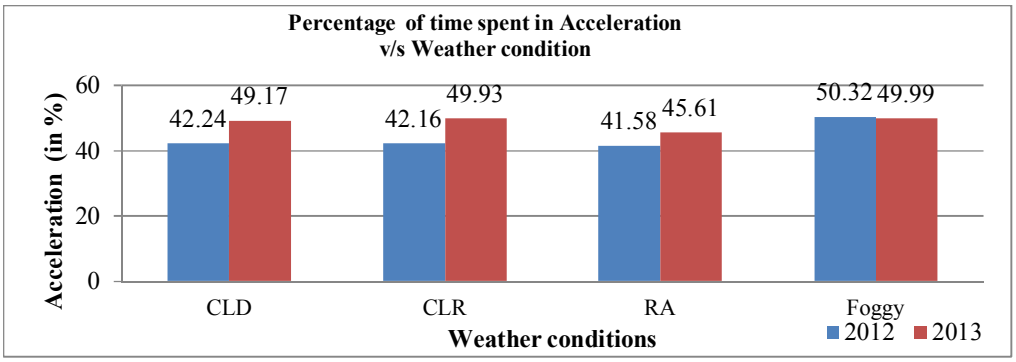

Figure 8: Percentage of time spent during Acceleration at different weather

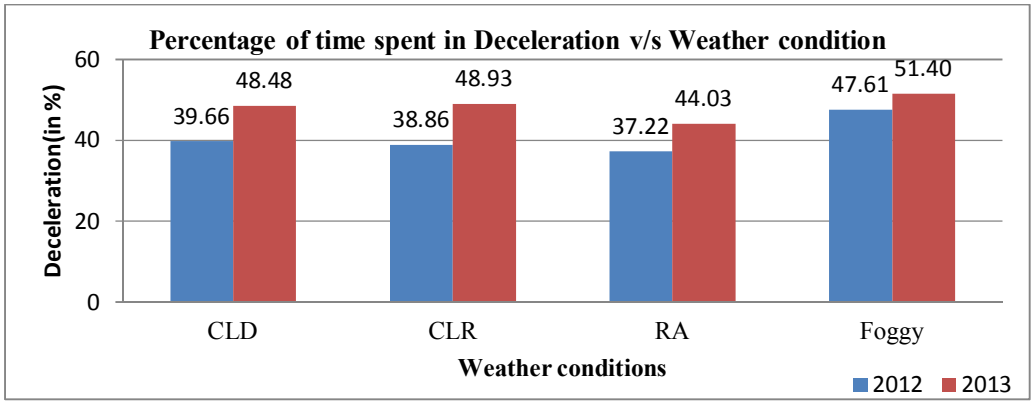

Figure 9: Percent time spent during Deceleration at different weather

The speed, travel time, percentage of time spent in acceleration & deceleration for all weather conditions during the year in 2012 and 2013 were measured (figure 5-9). The Speed showed variations in the same pattern for both of the years. It was observed that during rainy & foggy conditions traffic speed were observed almost same i.e. 40 km/hr as (figure 9). Travel time along the corridor was observed maximum during rainy season followed by cloudy, foggy and clear days in the year 2012. It was observed that travel time in the year 2013 was maximum in clear weather followed by cloudy, foggy and rainy weather (figure 9).

C. 4.3. Finding Possible Representative/Candidate Driving Patterns at Different Weather Conditions

From the study it was observed that out the average speed for each weather conditions cloudy (Vcld), clear (Vclr,) rainy (rain) and foggy days (Vfog) i.e.

$$Vcld = \sum_{i=1}^{n} \frac{V}{n} \quad \text{---------- eq.1}$$

$$Vclr = \sum_{i=1}^{n} \frac{V}{n} \quad \text{----------eq.2}$$

$$Vrain = \sum_{i=1}^{n} \frac{V}{n} \quad \text{---------- eq.3}$$

$$Vfog = \sum_{i=1}^{n} \frac{V}{n} \quad \text{---------- eq.4}$$

V as the average speed in both the directions

Hence, after that finding out the differential speeds i.e. V for each day for all weather conditions will be as follows:

$$\Delta V_{WC=1to4} = (V\,WC = 1to4 - V_{n=1\ to\ 4}) \quad \text{---------- eq.5}$$

Where WC implies for weather condition (WC) 1= cloudy, 2= clear, 3= rainy, 4=foggy

Tables (5) below show the all related Traffic, Human and Weather parameters for both of the years.

Table-5 Shows the parameters for the year 2012-2013

Date	Day	Speed	Weather Parameters				Driver Behaviour				
Date	Weather condition	Speed (Km/hr)	Temp (°C)	Wind Speed (km/hr)	HUM (%)	Average Pressure Barometer (mb)	Head movements (frequency)	yawning (frequency)	time taken while talking on mobile phone	talking with co-passengers	Age of Driver (years)
24/07/2012	Cloudy day	34	37	7	80	997	52	5	5	7	45
25/07/2012	Cloudy day	40.95	39	9	67	994	84	8	5	4	31
17/07/2012	Clear day	39	41	18	70	996	47	11	5	13	45
19/07/2012	Clear day	29.88	43	11	70	986	55	12	6	8	42
20/08/2012	Clear day	18.86	35	15	76	996	53	9	11	9	45
08-03-2012	Clear day	33.24	32	19	75	1046	85	6	6	8	28
08-08-2012	Clear day	38.37	37	7	50	1002	114	5	7	5	30

14/08/2012	Clear day	31.48	33	15	71	996	47	10	5	12	35
26/07/2012	Rainy Day	40.73	35	9	90	986	68	7	12	6	33
30/07/2012	Rainy Day	34.79	33	5	87	986	50	5	13	8	35
08-07-2012	Rainy Day	33.24	35	14	71	994	120	6	7	6	25
31/12/2012	Foggy day	13.62	13	3	32.0	1010.0	138	5	8	5	48
01-01-2013	Foggy day	34.31	15	2.2	30.0	1009.0	158	9	7	5	50
01-08-2013	Foggy day	40.65	12	3.0	40.0	1019.0	123	10	5	5	45
01-09-2013	Foggy day	34.42	13.7	2.2	57.0	1011.0	128	9	9	12	48
01-10-2013	Foggy day	31.53	8.3	2.0	39.0	1014.7	140	5	7	9	48
01-11-2013	Foggy day	9.4	23	5.0	10.0	1025.2	148	9	4	9	48

Table- 6 Shows the parameters for the year 2012-2013

Date	Day	Speed	Weather Parameters				Driver Behaviour				
Date	day	Speed (Km/ hr)	Temp (°C)	Wind Speed (km/h r)	Humi dity (%)	Average Pressure Baromet er(mb)	Head move ments (freq)	yawning frequen cy)	time (secs) in mobile phone	talkin g with co-passa ngers	Driv er's Age (yrs)
30/08/2 013	Cloudy day	28.52	34	6.5	90	994	73	13	11	9	25
09-02- 2013	Cloudy day	34.23	33.3	5	90	986	99	9	9	12	33
20/12/2 013	Cloudy day	27.96	13	5	80	996	118	5	7	5	47
23/12/2 013	Cloudy day	32.12	7	8	82	1010.0	77	10	5	12	29
29/08/2 013	Clear day	32.42	32.4	6	89	1000	65	14	6	11	25
09-03- 2013	Clear day	20.43	33.4	6	85	986	72	5	5	7	33
09-04- 2013	Clear day	21.61	34	7	91	1046	123	6	8	10	33
09-05- 2013	Clear day	18.68	33.1	7	90	994	94	8	5	6	33
28/08/2 013	Rainy Day	25.09	31.4	5	87	996	57	9	9	14	25
09-06- 2013	Rainy Day	32.42	33.7	6.3	93	986	78	7	12	6	33
09-09- 2013	Rainy Day	32.27	34.4	7	90	996	50	6	11	6	32
09-10- 2013	Rainy Day	30.31	12	7.5	90	1000	129	6	7	6	32
26/12/2 013	Rainy Day	27.96	10	6.5	80	1009.0	139	5	12	9	24

01-10-2014	Foggy day	29.1	8	8	70	1019.0	158	5	8	11	50
28/01/2014	foggy day	19.24	10	7	75	1011.0	127	9	6	5	27
29-01-2014	foggy day	19.85	9	5	70	1014.7	131	4	9	12	30
30/01/2014	foggy day	23.81	11	6	68	1025.2	149	5	7	10	27
31/01/2014	foggy day	32.87	6	7	65	1014.7	142	9	4	9	27

V. CONCLUSION & RECOMMENDATIONS

The findings of the present study reported the impact of adverse weather on speed profile. In the study driver's choice of speed during adverse weather conditions realistic field conditions were evaluated. The study has following major findings:

- Present study highlights the recorded average speed during adverse weather conditions were 34.1kmph, 47.7kmph and 63.25 kmph while driving at plain area for two, three and multiple lanes respectively and 48.0 kmph 56.6 kmph while ascending and descending the flyovers.
- Recorded Idling time was found more during rainy & cloudy weather conditions.
- Recorded speed and road signals violation of experienced drivers were found higher during simulated traffic as with more speed and irrespective to weather conditions as compared to the other group.
- Much of the research work pertaining to weather impact is obtained from studies outside India so it is also recommended that further researches in this area should be conducted to expand the limited knowledge about the impacts of weather on traffic flow on urban and non urban roads in India.

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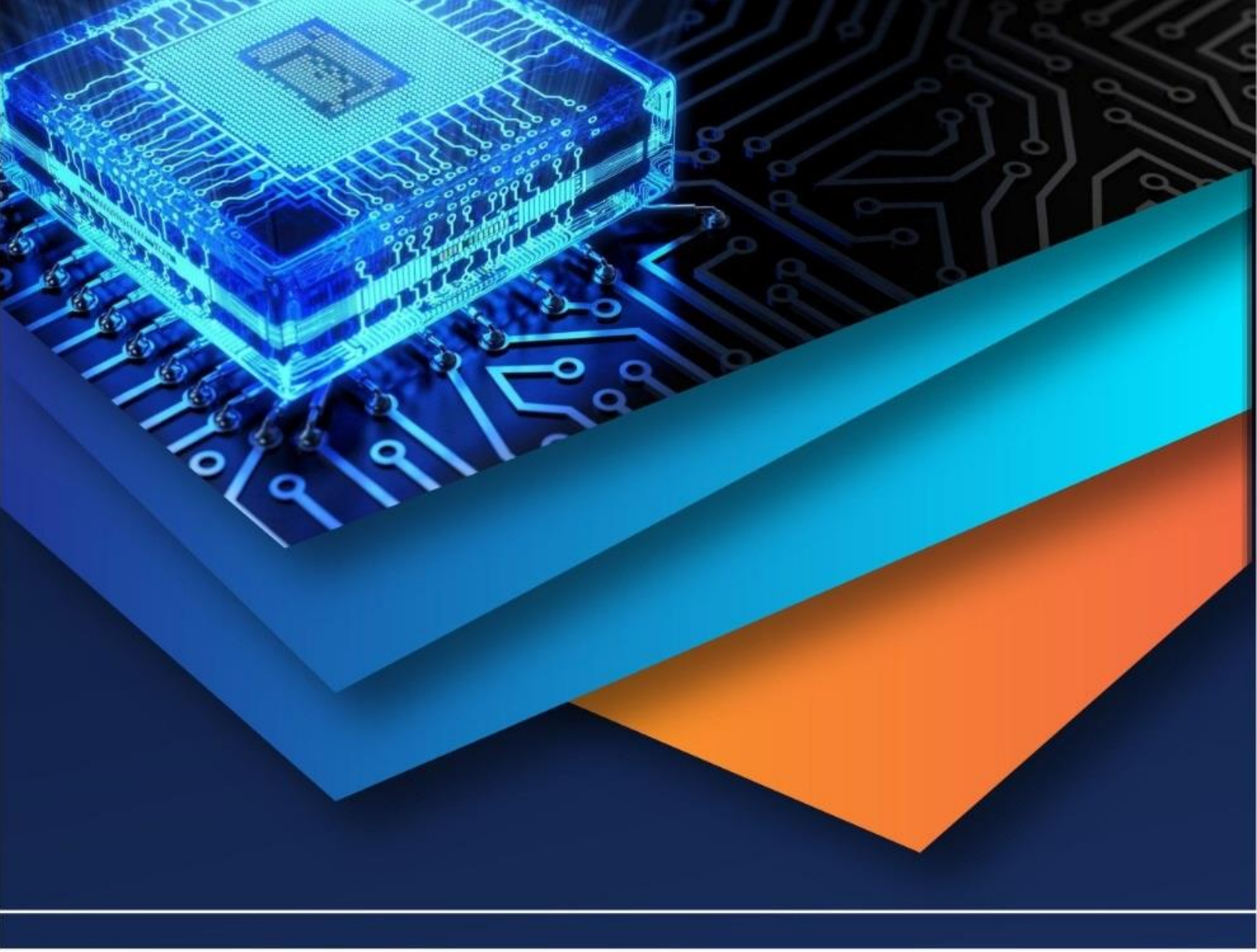

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