Modelling of Speed- Flow Equations on Four-Lane National Highway-8

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Abstract— The precise determination of relationship between speed and flow is essential for arriving at the capacity of a road. The Principal objective of the present study is to evaluate speed-flow relationships on National Highway-8 for different types of vehicles by developing separate speed-flow equations on NH-8.

Index Terms— Capacity, Flow, Free speed, Spot speed, Lane width, Speed-Flow equations.

I. INTRODUCTION

Transport sector plays a very significant role in improving the economic development of any country. Road transportation is the major component of the transport sector in India. India has one of the largest road networks in the world hovering around 3.4 million km at present. As per present estimate, total road network carry nearly 65% of freight and 85% of passenger traffic. Traffic on roads is growing at a rate of 7 to 10% per annum while the vehicle population growth is of the order of 12% per annum. Among them National Highways are the main arterial roads which run through the length and breadth of the country connecting ports, state capitals, industrial and tourist centers and neighbouring countries. About 40% of total road traffic is carried by the National Highways which is only 2% of the total road network. These will clearly indicate the congestion of traffic and drop in Level of Service (LOS) on our road network. For achieving optimal utilization of the road network in the country, the knowledge of highway capacity is of paramount importance.

The ***Microscopic approach*** is concerned with individual vehicular speed and spacing, while the ***Macroscopic approach*** deals with traffic-stream flows, densities, and average speeds. The various research studies conducted deploying these approaches have shown that these two approaches are interrelated. One type of model assumes that the relationship can be represented by a single function such as Greenshield's or Underwood's model. In such a case capacity can be estimated as the extreme point of the curve or curves representing the relationship. Such models may result in unreliable estimation of roadway capacity. Instead of using a single function, models in the recent past have tried to use different functions for different traffic flow regimes corresponding to uncongested and congested traffic conditions. In this case separate functions (either linear or non-linear) are fitted for these two regimes separately.

Manuscript Received January 2014.

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Travel speed is defined in this Manual as the space mean speed of light vehicles (LV) over the road segment as given below:

V = L/TT ----------(1)

Where:

V = space mean speed of LV (km/h)

L = length of segment (km)

TT = mean travel time of LV over the segment (h)

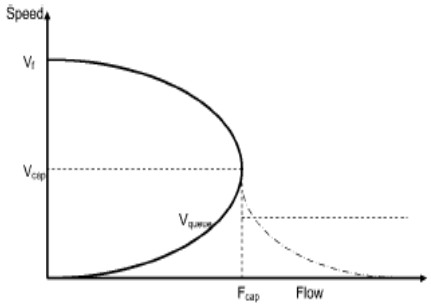

Fig. 1 Basic Speed-Flow Relationship

Normal Distribution And Normal Approximation:

The free speed data is generally analysed by fitting normal distribution curve and various percentile speeds are calculated form that they have listed below:

a) 15^{th} Percentile Speed (V_{15}):

It is defined as the speed below which 15 percent of all the vehicles travel. It is used to determine the lower speed limit on the major highway facilities such as Expressways. Vehicles travelling below this speed cause interference with the traffic stream and may cause hazards.

b) 50^{th} Percentile Speed (V_{50}):

It is defined as the speed at which there are as many vehicles going faster as there are going slower. It is also called as median speed.

c) 85^{th} Percentile Speed (V_{85}):

A speed value obtained from a set of field measured speeds, where only 15 percent of the observed speeds are greater

d) 95^{th} Percentile Speed (V_{95}):

It is defined as the speed below which 95 percent of all the vehicle travel and it is used as a design speed in geometric design. Sometimes 98^{th} percentile speed is also used for this purpose.

e) Spread Ratio:

The normality in a speed distribution curve can be better explained by the extent of spread in the speed data from its median value. The parameter, spread ratio, is used in this study to explain it. The Spread Ratio is defined as,

SR= $(V_{85}-V_{50})/(V_{50}-V_{15})$ **------(2)**

85^{th}, 50^{th} and 15^{th} percentile speeds of the section

can be determined from the Cumulative frequency of the speeds with defined interval.

II. LITERATURE REVIEW

(2009) Rahim F. Benekohal et. al. addresses traffic flow characteristics in Intelligent WZ and will determine methods for computing work zone capacity. Accurate determination of work zone capcity is very important because it significantly affects the speed and user's cost computations. Various ITS applications are implemented in the US (such as speed photo enforcement (SPE), dynamic lane management, variable speed control, travel time information display, dynamic rerouting, etc), but a major study to determine how traffic flow characteristics are affected in these intelligent WZ has not been conducted. This study investigated the fundamental relationship among traffic flow variables in a WZ where ITS was implemented for mainly as a speed control measure. A theoretical relationship was developed using field data collected in work zones.

(2010) Satish Chandra et. al. made an attempt to determine the effect of shoulder width anf traffic composition on speed-flow characteristics and hence capacity of intermediate lane roads. The data were collected at ten sections located in three states viz. Uttarakhand, Gujarat and kerala. Results indicate that capacity of an intermediate lane road is around 2000 PCUs/h which is more than the suggested capacity value of 1200 PCUs/h in IRC: 64-1990.

(2011) Kivanc A. Avrenli et. al. has found the results which shows both the police enforcement and SPE led to significant changes in the work zone speed-flow curve compared to only MUTCD signage conditions. The general shape of the speed-flow relationship inside the work zone was similar to the speed-flow curve under basic freeway conditions, but the ending point of the upper branch of the curve occurred at lower traffic flow rates and the rate of the decrease in speed was higher. The speed-flow curve for the Manual of Uniform Traffic Control Devices (MUTCD) signage-only case returned a work zone capacity of around 1,850 passenger cars per hour per lane (pcphpl). Compared to that speed-flow curve, both the police enforcement and SPE moved the upper (uncongested) branch of the speed-flow curve downward, which caused a work zone capacity reduction of about 50 pcphpl in the case of police enforcement and 100 pcphpl in the case of SPE implementation. The results obtained through this study reveals the distinct effects of police enforcement and ITS on work zone capacity. Accurately estimating the capacity of work zones with different speed reduction treatments provides more efficient operation in a real-time system, more accurate diversion and traveler information for alternate routing, improved reliability of the system, and better understanding of the traffic flow characteristics in work zones.

(2011) Ibrahim Hassan Hashim has presented an analysis into speed characteristics on rural two-lane highways under existing conditions. Empirical data from several study sites on intercity rural two-lane roads in Minoufiya Governorate, Egypt were used in this investigation. Three separate however relevant analysis are presented in this paper. The first analysis investigates the relationship between 85th percentile speed and headway to define a headway value corresponding to free moving vehicles. The second analysis examines the suitability of the posted speed limits on the roads under study. The third and last analysis inspects the conformity of the study sites' speed data with normal distributions. It was found that the 85th percentile speed took a constant value at headway equal to 5 s or more. Also, a significant proportion of drivers exceed the posted speed limit as well as the current speed limit may not be appropriate. Finally spot speed data follow a normal distribution.

III. METHODOLOGY

For estimating the capacity, speed and flow data is essential. Following survey have been conducted :

- ***Spot-Speed survey*** : By Pro-laser Instrument like Doppler Radar.
- ***Speed-Flow survey*** : Volume counts By Manual method.

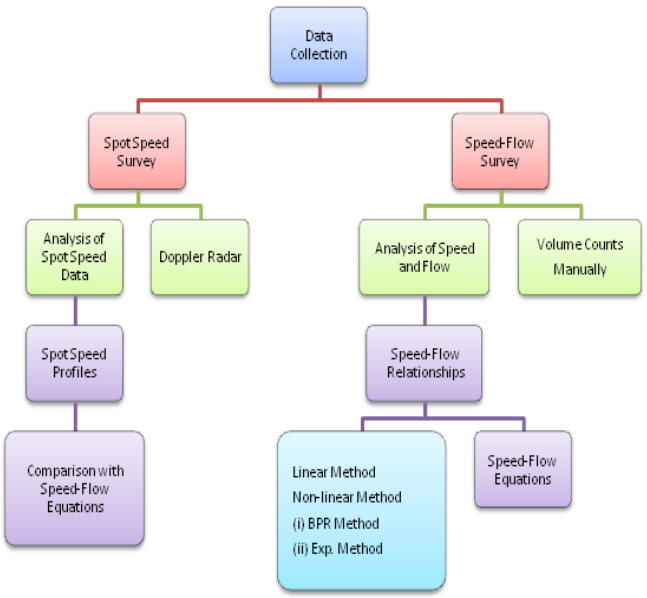

Fig. 2: Flow-Chart of Methodology

Methodology For Spot Speed Survey:

The observed free speeds of different vehicle types cab be classified into suitable intervals of 5 kmph to determine the frequency distribution of vehicles as per speed. The time mean speed and standard deviation values can be calculated from the frequency distributions. Further, an attempt has been made to check the validity of the data by fitting the normal distribution curves on the observations using the mean and standard deviations of the appropriate vehicle speeds.

METHODOLOGY FOR SPEED-FLOW ANALYSIS:

The following methods can be adopted for speed-flow analysis:

1. Linear Method
2. Non-Linear Method
   - BPR Equation
   - Exponential Equation

In the present study, the speed-flow data can be analysed by dividing entire region into two parts. They are

(i) Uncongested (Upper Part): Traffic related to Uncongested and Queue Discharge states

(ii) Congested (Lower Part): Traffic related to Queuing state (Stop and Go)

These parts in the speed-flow analysis is shown in Figure 3

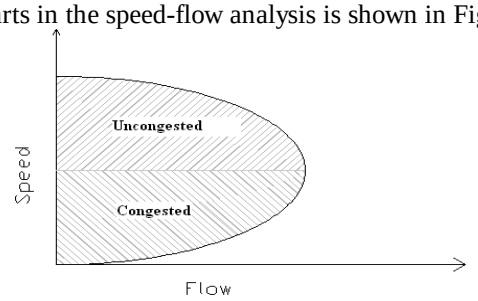

Fig 3: Uncongested and Congested parts of Speed-Flow Curve

IV. DATA COLLECTION:

STUDY AREA

In the present study, Spot speed and Speed-flow data are collected on National Highway-8 i.e between **Vadodara and Vasad**. Data was observed on both direction of travel. These sections include Four-Lane carriageways, but separate analysis has to be carried out for these carriageways. Using the collected data at these sections, speed-flow analysis can be carried out.

SPOT SPEED DATA

The Spot speed data was collected on National Highway-8. (between Vadodara and Vasad) The Doppler Instrumentation were employed to record the spot speeds as shown in Figure 11.

Fig. 4: Doppler Radar

Doppler Radar Instrument works on the Principle of sending out invisible laser beam pulses(per second) and recording the time taken to receive the pulses back from the object in motion. Proper care was taken to protect this instrument system from the view of passing traffic.

Table 1: Spot Speed Data at NH-8 using Doppler Radar

SR. NO.	VEHICLE TYPE	OBSERVED SPEED RANGE IN K.P.H.
1.	AUTO	40-60
2.	TWO-WHEELERS	45-75
3.	SMALL CARS	50-90
4.	BIG CARS	50-95
5.	LIGHT COMMERCIAL VEHICLES	40-70
6.	TWO-AXLE TRUCKS	45-80
7.	MULTI-AXLE TRUCKS	40-65
8.	BUSES	50-75

Traffic Volume Counts:

The Traffic Volume counts were carried at NH-8 i.e days. The volume counts were taken on pre-designed form. The classified volume counts includes fast moving vehicles such as small cars, big cars, small cars, buses, two axle-trucks, multi axle trucks, Autos and Two-wheelers and slow moving vehicles such as cycle and animal drawn vehicles between Vadodara and Vasad in order to asses time-wise variation of traffic volume. Traffic Volume counts were planned and conducted for 7 hours on Normal working day.

Table 2: Traffic Volume Count data on NH-8

Time of the Day		Two-Wheelers	Autos	Small Cars	Big Cars	Cycles	Buses	Tractors and Trailors	LCV	Two Axle Trucks	Multi-Axle Trucks	PCU/15 min
From	To											
	From Vadodara to Vasad											
PCU		0.5	0.5	1	1	0.5	3	3	1	3	3	
9:00	9:15	122	33	78	22	0	5	4	26	20	7	311.5
9:15	9:30	139	26	92	26	2	6	3	56	21	6	365.5
9:30	9:45	163	40	83	32	0	6	2	20	38	5	389.5
9:45	10:00	141	40	74	32	0	5	5	28	31	6	365.5
10:00	10:15	84	18	33	27	0	4	2	12	26	10	249
10:15	10:30	119	40	99	24	0	9	3	28	22	9	359.5
10:30	10:45	108	44	69	20	0	7	4	35	47	15	419
10:45	11:00	171	43	100	21	2	11	5	42	98	26	691
11:00	11:15	48	18	34	17	3	2	1	11	7	3	135.5
11:15	11:30	57	24	79	27	0	6	0	26	27	8	295.5
11:30	11:45	71	35	68	24	0	7	4	21	23	16	316
11:45	12:00	81	43	65	25	4	4	3	36	31	10	334
12:00	12:15	73	30	51	18	1	5	1	34	42	7	320
12:15	12:30	61	24	62	24	2	12	3	29	59	12	416.5
12:30	12:45	75	33	77	29	1	8	4	38	67	14	477.5
12:45	13:00	57	41	82	35	3	14	3	33	49	9	425.5

13:15	13:30	64	35	71	27	2	4	4	25	43	13	365.5
13:45	14:00	71	30	103	41	3	9	5	41	58	11	486
14:15	14:30	59	22	93	29	1	7	3	31	69	14	473
14:30	14:45	65	41	110	42	2	7	4	29	81	16	559
14:45	15:00	72	27	81	18	3	2	0	37	74	11	448
15:00	15:15	88	24	79	27	0	6	1	20	61	8	410
15:15	15:30	118	35	65	24	0	7	2	31	51	12	412.5
15:30	15:45	106	42	74	25	2	4	3	36	31	9	351
15:45	16:00	98	51	81	21	0	6	0	29	37	13	373.5

Table 3: Traffic Volume Count data on NH-8

Time of the Day		Two-Wheelers	Autos	Small Cars	Big Cars	Cycles	Buses	Tractors and Trailors	LCV	Two Axle Trucks	Multi-Axle Trucks	PCU/ 15 min
From	To											
	From Vasad to Vadodara											
PCU		0.5	0.5	1	1	0.5	3	3	1	3	3	
9:00	9:15	71	62	30	22	1	12	6	35	57	21	442
9:15	9:30	72	49	42	22	2	6	4	32	56	26	433.5
9:30	9:45	108	62	45	26	1	9	3	37	72	31	538.5
9:45	10:00	78	68	62	12	3	14	5	43	92	33	623.5
10:00	10:15	113	39	47	11	2	10	2	25	87	23	526
10:15	10:30	98	35	26	5	0	11	3	31	82	13	455.5
10:30	10:45	113	48	84	8	1	7	0	39	62	17	470
10:45	11:00	121	39	70	14	0	6	1	18	51	6	374
11:00	11:15	116	43	37	11	3	5	3	16	56	17	388
11:15	11:30	113	34	47	15	0	7	2	27	80	22	495.5
11:30	11:45	104	43	55	16	0	10	2	32	75	20	497.5
11:45	12:00	122	45	50	11	0	8	1	22	105	27	589.5
12:00	12:15	127	33	78	22	1	5	6	39	91	31	618.5
12:15	12:30	141	26	81	22	0	9	2	32	76	23	548.5
12:30	12:45	97	31	77	19	0	6	4	45	87	19	553
12:45	13:00	81	40	74	24	1	5	1	36	97	25	579
13:15	13:30	72	33	58	15	0	11	2	49	90	21	546.5
13:45	14:00	79	39	61	11	0	9	1	31	88	31	549
14:15	14:30	64	36	84	8	1	7	0	37	78	19	491.5
14:30	14:45	59	39	70	10	0	6	1	44	102	24	572
14:45	15:00	79	43	54	13	0	5	3	27	94	17	512
15:00	15:15	75	42	59	15	0	9	2	35	80	22	506.5
15:15	15:30	84	37	55	22	0	7	2	39	75	20	488.5
15:30	15:45	104	45	62	11	1	10	1	28	68	27	494
15:45	16:00	95	41	43	9	0	9	1	34	61	21	430

I. DATA ANALYSIS

The speed data considered for Two Wheeler, Auto, Bus, Car, goods vehicles and multi-axle vehicles are approximately more than 65 kmph, 50 kmph, 60 kmph, 80 kmph, 60 kmph and 55 kmph respectively

Table 4: Spot Speed of Vehicles on Section of Vadodara-Vasad

Vehicle Type	Sample Size	Avg. Speed	V_{15}	V_{50}	V_{85}	V_{95}	Max. Speed	Standard Deviation	Coefficient of Variation (%)
Auto	34	42.48	37.4	38.1	45.5	50	70	3.91	9.2
Two Wheeler	82	58.24	48	56.2	64.7	68.2	75	8.06	13.83
Small Car	129	75.11	63	73.1	82.8	90	90	9.56	12.72
Big Car	117	77.63	62.3	72.3	82.6	95.2	100	9.8	12.62

Bus	31	56.4	42.4	44.6	51.9	55.3	65	4.58	8.12
LCV	75	47.32	41.7	45	53.5	57.4	70	5.7	12.04
Two Axle Vehicle	84	56.35	51.3	55.1	58.4	63.3	80	3.43	6.08
MAV	59	48.1	42.4	43.4	48.9	55.3	65	3.14	6.52

Table 5: Spot Speed of Vehicles on Section of Vasad-Vadodara

Vehicle Type	Sample Size	Avg. Speed	V_{15}	V_{50}	V_{85}	V_{95}	Max. Speed	Standard Deviation	Coefficient of Variation (%)
Auto	31	51.53	43.3	49.3	56.3	60	70	6.28	12.18
Two Wheeler	67	63.71	58.1	65	72.6	77.9	80	7	10.98
Small Car	107	77.28	68.4	75.2	82.5	85.3	100	6.81	8.81
Big Car	96	76.95	68.1	74.9	79.9	81.7	100	5.7	7.4
Bus	22	56.47	48.3	52.9	60.2	65.2	80	6.85	12.13
LCV	79	49.01	41.3	46	53.3	58.3	70	5.79	11.81
Two Axle Vehicle	94	55.4	47.6	52.3	59.9	65	65	5.94	10.72
MAV	53	48.23	42.3	44.1	51.2	57.5	65	4.3	8.91

Note: Speed is in KPH

The classified traffic volume counts were carried at the selected locations in order to assess the time-wise variation of traffic volume. The observed traffic composition on 4-Lane divided carriageways is presented in Figure 5.1.

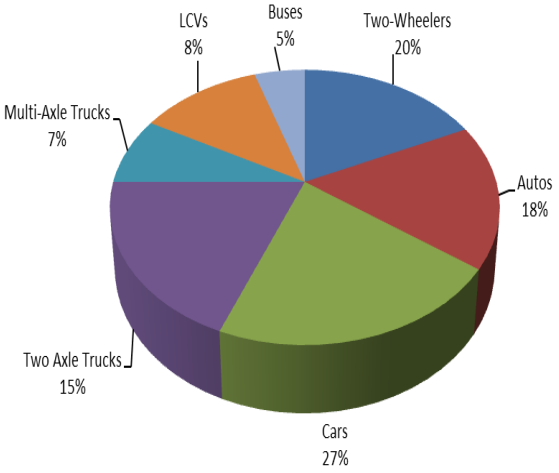

Figure 5: Traffic Composition on NH-8

Table 6: Speed-Flow Equations for Upper & Lower Part

Sr. No.	Vehicle Types	Upper Curve		Lower Curve	
		Linear	Non-Linear	Linear	Non-Linear
1	Two wheeler	y=0.123x+56.475 R^2=0.156	y=80.116/(1+2.4589*(x/7000)^1) R^2 = 0.83487	y = 0.056x +50.799 R^2 = 0.162	$y=19.966863e^{0.000257x}$ R^2=0.75876
2	LCV	y=0.552x+39.185 R^2=0.994	y=71/(1+1.7067*(x/6999.908)^1.154) R^2 = 0.737	y = 0.529x +38.482 R^2 = 0.995	$y = 21.385206e^{0.000177x}$ R^2 = 0.884545
3	Two Axle Vehicle	y=0.537x+44.301 R^2=0.999	y=69/(1+1.099*(x/7000.0012)^1.049) R^2 = 0.678	y = 0.528x +43.928 R^2 = 0.999	$y = 20.614976e^{0.000157x}$ R^2 = 0.714434
4	Car	y=0.655x+48.111 R^2=0.996	y=95/(1+1.7851*(x/6999.125)^1.802) R^2 = 0.77809	y = 0.635x +47.391 R^2 = 0.996	$y = 21.83551e^{0.000164x}$ R^2 = 0.741320
5	MAV	y=0.524x+39.480 R^2=0.992	y=60.4605/(1+1.1644*(x/6999.93)^1.354) R^2 = 0.66073	y = 0.508x +39.022 R^2 = 0.997	$y = 18.087490e^{0.000261x}$ R^2 = 0.670439
6	Bus	y=0.611x+49.024 R^2=0.991	y=74/(1+2.867*(x/6998.75)^2.29) R^2 = 0.62124	y = 0.573x +48.235 R^2 = 0.992	$y = 19.040580e^{0.000335x}$ R^2 = 0.634477
7	Auto	y=2.01x+76.361 R^2=0.997	y=59.096/(1+2.5*(x/6000)^1) R^2 = 0.89165	y = 1.94x +79.71 R^2 = 0.997	$y=7.513635e^{0.001052x}$ R^2=0.929601

VI. MODELLING SPEED-FLOW EQUATIONS:

VII. CONCLUSION

The following conclusions are drawn from the present study:

- The composition of traffic clearly indicates the influence of city area on rural road. The highest and average speed of various types of vehicles are too high then city area because of the distance from CBD area.
- Separate Speed-flow equations for Uncongested and Congested parts are developed for four lane divided carriageways. From the statistical results, it can be said that these equations can predict realistic capacity values as their R^2 values are very good coupled with low value of the standard error of the coefficient and the constant. It indicates that developed speed-flow equations are consistent.
- Considering this, the speed - flow equation developed using for cars (having the PCU value of 1) can be used with assurance for fixing capacity norms of multi-lane highways on Indian roads.

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