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SPEED-FLOW-DENSITY STUDY OF DIFFERENT ROADS AND THEIR COMPARISONS

Er. Sourbh[1], Er. Deepak Mathur[2]

Civil Engineering Department, Kautilya Institute of Technology and Engineering, Rajasthan, India

[1]sourbhjhanwar17@gmail.com, [2]mathurdeepak1507@gmail.com

Abstract: An expanding vehicular growth in urban area is fact, so the facility to transportation should be adequate for road users. Development of relationship between speed density- flow is the fundamental for knowing the traffic condition. All vehicles are of different size, shape, power, load carrying capacity and speed. A traffic flow characteristic is affected by vehicle composition, width of road and other physical and traffic factors. To estimate the capacity of road, same factors are influencing to traffic flow. Four urban road stretches of Jaipur city are taken for developing speed-density relationship and flow- density relationship. Four roads namely Mahal Road, Haldighati Marg, Kumbha Marg and Goner Road with a particular stretch of road are considered for developing this relationship. Data is collected over seven days and then average is taken for calculation. R^2 are also calculated to validify the good relationship. Classified volume and speed are collected from the field data. Mahal Road: Exhibited the highest free-flow speed (32.98 km/hr) and maximum density (162 vehicles/km). These factors indicate smoother traffic flow due to better geometric design, wider lanes, or fewer interruptions. Indian road way condition is having heterogeneity and leads to many problems for estimating traffic flow parameters.

Key words: **Classified volume, Space mean speed, PCU, Density**

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1. INTRODUCTION

1.1 General

The road transport mode in India has come to occupy a pivotal position in the overall transport system. Over the past five decades, the share of road transport in overall traffic flows has been continually increasing with a substantial shift from rail to road being observe.

The road transport sector in India has expanded manifold in fifty years after independence, both in terms of spread and capacity. The growth in the importance of road transport within the transport sector is borne out by its growing share in GDP. The share of road transport in GDP is presently 3.69 per cent which accounts for a major share of all transport modes which contribute 5.5 per cent to GDP and handles more than 60 percent of the freight and more than 80 percent of the passenger traffic in India.

The Indian Road network is seemingly very large. However, only 47 per cent of the roads are paved. The high-density corridors of road linking metro cities and ports are crowded and are carrying traffic more than capacity. About 14,000 kms of National Highway require four laning, while 10,000 kms require widening from single lane to two- lane to facilitate normal flow of existing road traffic. The average productivity of a truck is 200 kms a day as against 350- 400 kms that would be possible through reduction of congestion. The demand for transport is affected by structural changes taking place in the economy. This growth in transport demand has to be met by expanding domestic supply as transport infrastructure is non tradable. Investment in transport must reflect the need to make up for existing capacity shortages and also to allow for growth in demand.

1.1.1 Motor Vehicle Population: There has been a staggering 100-fold increase in the population of motorized vehicles; however, the expansion in the road network has not been commensurate with this increase. While the motor vehicle population has grown from 0.3 million in 1951 to over 30 million in 2004, the road network has expanded from 0.4 million km to 3.32 million km, only a 8 fold increase in terms of length during the same period. However, upgrading of roads by way of widening of carriage- ways, improved surface quality, strengthening/ reconstruction of old/ weak bridges and culverts, etc. has been carried out.

1.1.2. Speed flow density Heterogeneous traffic on Indian Roads Categories Roadway capacity values and speed-&flow relationships used for planning, designing and operating roads, in most of the developed countries, pertain to fairly homogeneous traffic conditions comprising vehicles of more or less uniform static and dynamic characteristics. However, traffic scenario in developing countries like India differs significantly from conditions observed in developed countries. Road traffic in India is highly heterogeneous comprising vehicles of wide-ranging physical dimensions, weight and dynamic characteristics.

2. LITERATURE REVIEW

2.1 GENERAL

The three parameters flow, speed and density help in determining the traffic flow. The relations in between speed, flow and density are known as fundamental diagrams which gained more attention since Greenshields found a numeric model in 1935. A linear relationship exists in between speed and density. Recent studies involve mainly the relationships in between the speed- flow – density, definition of traffic flow parameters and nature of fundamental diagrams. Among the above three definition of traffic parameters plays a vital role because it is the basic analysis of traffic phenomenon. The traffic conditions are particularly divided in to three different categories, namely uncongested, queue discharge and congested. In previous studies the flow density relation is used for examining the qualitative signature.

(Gaurav Verma, Saurabh Jaglan, Naveen Kumar, 2024) [1] Urban and interstate speed restrictions are mainly enacted to improve road safety, efficiency, and the reduction of travel time and accidents. When evaluating the capacity and free-flow conditions of interurban roads, the 85th percentile of free-flow speed is a regularly used metric. With the use of volume and speed data, this study endeavours to estimate the capacity of four-lane inter-urban highways in Telangana. Moreover, it investigates, taking into account vehicle kinds and speed restrictions, the connection between density, capacity, flow, and speed. Two lengths of inter-urban highways close to Hyderabad were measured for free-flow speeds; these segments included both straight and curving parts of the route. The results show that in Hyderabad, automobiles, lorries, and buses make up the majority of traffic, with two-wheelers coming in second. Volume and speed

capacity analysis becomes essential for understanding the density and flow of different vehicles on specific stretches of the road. Estimating capacity is a fundamental aspect of designing, operating, and planning the "layout of a road network system. The estimation of road capacity, as outlined in the Highway Capacity Manual (HCM) of 2010, relies significantly on the free-flow speed. This speed, indicative of a situation where vehicle movement remains unaffected by the presence of other vehicles in the stretch, holds a pivotal role in capacity assessment. However, the quantification of the influence of free-flow speed on four-lane inter-urban roads is not explicitly addressed in existing methodologies. The heterogeneous nature of traffic on Indian highways, coupled with poor lane discipline, poses challenges for applying simulation techniques. On other hand, values of the Passenger car unit (PCU)" which change homogeneous traffic streams to heterogeneous traffic into a more standardized form. However, PCU values are dynamic and vary under different traffic conditions, necessitating complicated and expensive data collection procedures. A model is suggested in this study which aims to provide a quick estimation of capacity, removing complexities associated with traditional methodologies, while ensuring accuracy is maintained. This model aims to address the challenges posed by heterogeneous traffic on Indian highways and streamline the estimation process, making it more accessible for field engineers. The model efficiently estimates the capacity of inter-urban roads in Telangana by utilizing speed data and exploring the relationships between flow, speed, density, and capacity.

(Sandeep Singh, S. Moses Santhakumar, 2021) [3] Many researchers have concentrated on analysing the traffic characteristics of the highway segments as a whole rather than considering individual lanes. Hence, in the present study, a comparison of the lane-based vehicle speeds and estimation of lane-based Dynamic Passenger Car Unit (DPCU) is carried out. Later, the estimated DPCU values for vehicles on Median Lane (ML) and Kerb Lane (KL), as well as the entire roadway (RW), are compared with the Indo-HCM:2017, and IRC-64:1990 suggested DPCU and PCU values, respectively. An enormous amount of traffic-related field data was collected using the infra-red sensor technique at the different highway mid-block sections in India. The macroscopic fundamental relationship diagrams among speed, flow, and density under different highway lanes such as ML and KL, and the RW, are established using the Greenshields

Linear Model to determine the lane-based (ML and KL) and RW capacity. The study results reveal that the capacity estimated using the Indo-HCM:2017 and IRC-64:1990 suggested DPCU and PCU values, respectively, overestimated the lane-based capacity but underestimated the RW capacity compared to the capacity estimated using the DPCU values in this study. The analysis results also show a distinct difference between speed and DPCU values for the vehicles in different lanes and RW. Hence, proving that the assumption and use of RW speed, DPCU, and capacity values without considering the individual lanes as erroneous. The findings from this study emphasize the importance of taking lane-based characteristics into account rather than complete RW characteristics, thus addressing significant shortcomings in the previous studies.

3. RESULT AND ANALYSIS:

3.1 Determination of Study Section

The initial step was the selection of the road stretch, from which the data were collected. The road selected was Mahal Road (see Fig.3.1). The next step was the selection of the study section on the selected road in which the entry point and exit point are marked. A pilot study was organized on the selected road which covers both free-flow and congested-flow conditions in order to determine the place were predictable to get the data more precisely. The distance enclosed by the entry and exit point is noted as 1.1 km. The data were collected by videographic survey conducted on typical weekdays over peak and off-peak hour.

3.1.1 Traffic Data for Mahal Road:

Table 3.1 Average Hourly Traffic data of Mahal Road

PCU	0.75	2	1	2.2	0.4	Flow				
Time (min)	T/W	Three-wheeler	Car	Bus	Cycle	vehicle/ hour	Vehicle/5 min	PCU/Hr.	Speed	Density
5	160	41	95	0	2	3564	297	3564	31.47	113.6
10	136	36	104	2	5	3388.8	282.4	3388.8	31.31	108.46
15	167	48	107	2	3	3991.8	332.65	3991.8	31.47	124.69
20	183	41	93	1	0	3773.4	314.45	3773.4	31.05	122.89
25	158	38	87	1	4	3404.4	283.7	3404.4	31.84	108.54
30	171	49	94	1	12	3869.4	322.45	3869.4	31.83	123.27

35	191	51	82	1	15	3953.4	329.45	3953.4	31.79	128.34
40	166	38	105	1	4	3692.4	307.7	3692.4	27.88	135.15
45	177	32	100	1	4	3587.4	298.95	3587.4	27.3	138
50	182	58	112	1	8	4400.4	366.7	4400.4	26.74	162
55	162	60	103	0	9	4134	344.5	4134	32.98	121.52
60	186	28	117	1	15	3776.4	314.7	3776.4	28.96	143.78
Total	**2039**	**520**	**1199**	**12**	**81**	**45535.8**	**3794.65**	**45535.8**		

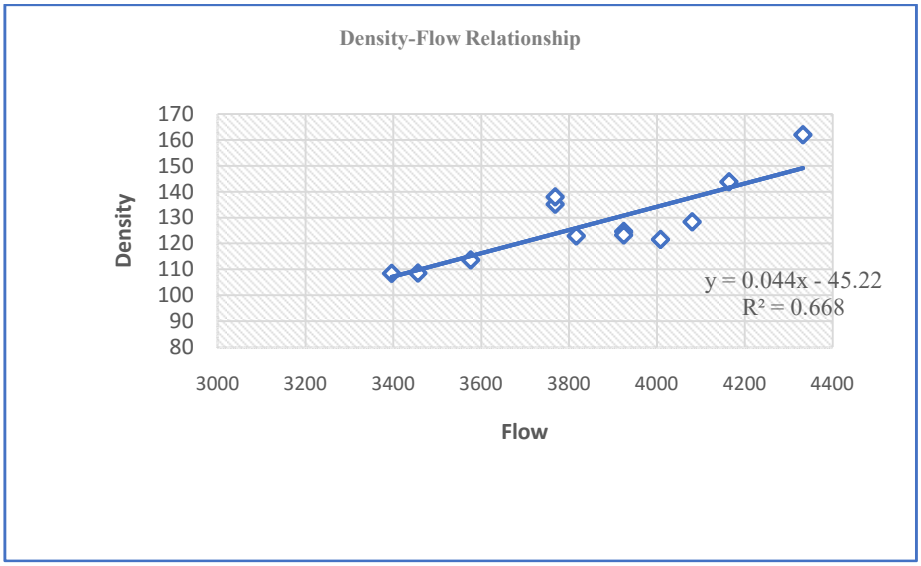

Figure.3.1. Graph showing density-flow relationship

Density-Flow linear relationship (model 1) is estimated and the relationship is developed using excel programme for Mahal Road $y=0.0449x-45.224$ $R^2 = 0.668$

The R square value of model (1) is 0.668, which indicates good relationship between data of speed and density for the Mahal Road.

Where,

y= Speed in Km/hr

x= Density in vehicles/km

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3.1.2 Traffic Data for Haldighati Marg:

Table 3.2 Average Hourly Traffic data of Haldighati Marg

PCU	0.75	2	1	2.2	0.4				1.4 km
Time (min)	T/W	Three-wheeler	Car	Bus	Cycle	vehicle /5 min	vehicle/hour	Speed	Density
5	147	43	103	2	2	297	3564	13.20	110
10	125	52	99	1	5	282	3388.8	13.20	110.00
15	167	39	120	4	3	333	3991.8	13.20	100.00
20	156	45	103	5	6	315	3773.4	13.20	106.36
25	139	32	107	2	4	284	3404.4	13.19	92.73
30	179	39	89	3	12	322	3869.4	13.20	90.90
35	155	43	108	8	15	329	3953.4	13.21	66.36
40	158	39	102	5	4	308	3692.4	13.24	70.90
45	156	31	103	5	4	299	3587.4	13.19	68.20
50	186	56	102	8	15	367	4400.4	13.21	116.36
55	181	50	94	7	14	345	4134	13.22	104.55
60	148	46	102	4	15	315	3776.4	13.20	80.00
Total	1897	515	1232	54	99	3796	45535.8		

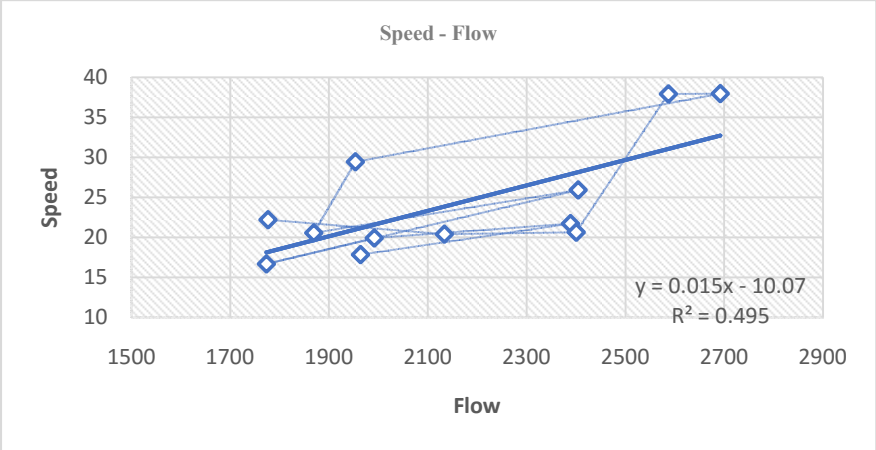

Figure.3.2. Graph showing speed-flow relationship

Similarly, Speed-Flow linear relationship (model 2) is estimated and the relationship is developed using excel programme for Y =0.0159x - 10.077 R^2 = 0.4955. The R square value of model (2) is 0.4955, which indicates good relationship between data of speed and density for the Haldighati marg.

3.1.3Traffic Data for Kumbha Marg:

Table 3.3 Average Hourly Traffic data for Kumbha Marg

PCU	0.75	2	1	2.2	0.4		Traffic Flow		1.25 km
Time (min)	T/W	Three-wheeler	Car	Bus	Cycle	vehicle /5 min	vehicle/hour	Speed	Density
5	50	21	53	6	10	140	1680	23.3333333	72
10	68	19	58	5	8	158	1890	20.106383	94
15	104	12	41	5	6	168	2010	21.6129032	93
20	86	17	39	2	4	148	1773	20.6162791	86
25	59	9	42	1	6	117	1404.4	30.5304348	46
30	103	46	208	1	12	156	1869.4	20.1010753	93
35	78	23	42	1	19	163	1953.4	20.4544503	95.5
40	68	17	39	10	7	141	1692.4	20.8938272	81
45	49	21	55	3	4	132	1587.4	19.7930175	80.2
50	39	14	45	9	10	117	1400.4	16.3789474	85.5
55	91	17	54	4	12	178	2134	21.7755102	98
60	61	23	39	10	15	148	1776.4	23.3736842	76
Total	856	239	715	57	113	1766	21170.8		

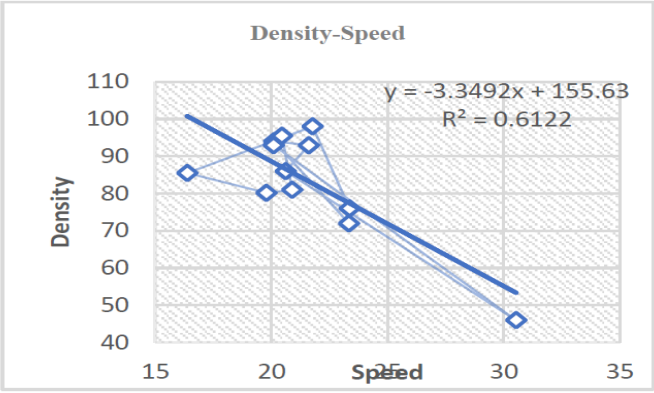

Figure.3.2. Graph showing speed-flow relationship

Speed-Density linear relationship is estimated and the relationship is developed using excel programme for Kumbha Marg. Y = -3.3492x + 155.63

R^2 = 0.6122. The R square value is 0.6122, which indicates good relationship between data of speed and density for the Kumbha marg.

3.1.4 Traffic data for Goner Road:

Table 3.4 Traffic Data for Goner Road

PCU	**0.75**	**2**	**1**	**2.2**	**0.4**		**Flow**		0.85 km
Time (min)	**T/W**	**Three-wheeler**	**Car**	**Bus**	**Cycle**	**vehicle /5 min**	**vehicle/ hour**	**Speed**	**Density**
5	54	19	49	4	4	**130**	1560	19.375	80
10	59	21	51	1	6	**138**	1656	20.2439	82
15	47	19	47	4	3	**120**	1440	20.45714	70
20	44	24	60	3	5	**136**	1632	18.24444	90
25	57	30	56	6	7	**156**	1872	25.78082	73
30	79	14	57	6	12	**168**	2016	29.58824	68
35	52	32	67	6	7	**164**	1968	30.84375	64
40	54	19	59	2	4	**138**	1656	23.02778	72
45	51	21	47	2	9	**130**	1560	29.80769	52
50	67	12	57	8	14	**158**	1896	18.0381	105
55	60	32	65	1	10	**168**	2016	23.21839	87
60	48	13	55	2	12	**130**	1560	24.8254	63
Total	672	256	670	45	93	1736	20832		

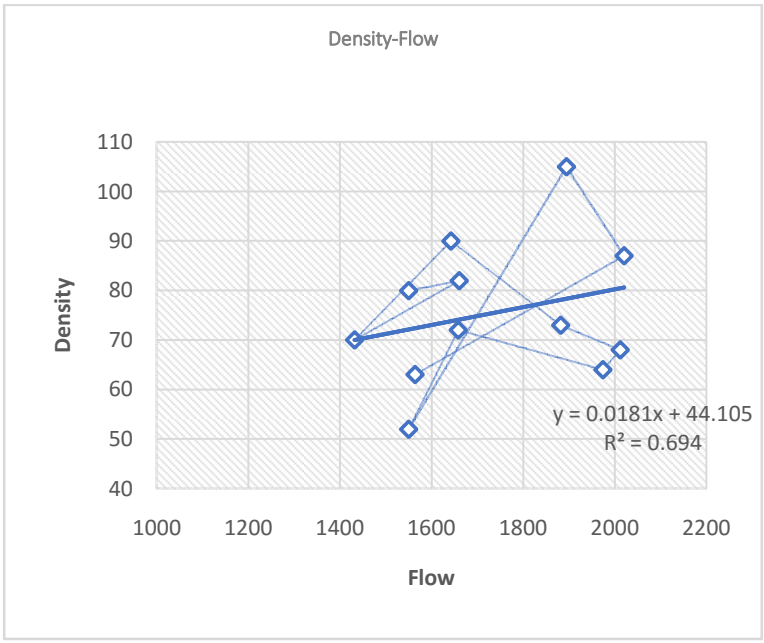

Figure.3.4. Graph showing Density- Flow Relationship

Similarly, Density-Flow linear relationship is estimated and the relationship is developed using excel programme for Goner Road $y = 0.0181x + 44.105$ $R^2 = 0.694$. The R square value is 0.694, which indicates good relationship between data of speed and density for the Goner Road.

4. CONCLUSION AND FUTURE SCOPE

4.1 Conclusion

Traffic flow is heterogeneous in India. The lane discipline is not followed. In the present study, traffic flow parameter i.e. speed-density is developed. The speed-flow-density study of the four different roads has provided valuable insights into their operational performance and traffic characteristics. The key findings can be summarized as follows:

The relationship between speed, flow, and density on four roads followed the fundamental principles of traffic flow theory, with notable differences due to road design, traffic composition, and external conditions.

Except One road Haldighati Marg all other roads are exhibited higher free-flow speed, indicating better capacity to handle lighter traffic volumes, likely due to superior geometric design or fewer obstructions.

The road experienced earlier capacity breakdown, reflecting its limitations under high-density conditions, potentially due to narrower lanes, poor surface quality, or higher traffic friction.

1. The relationship is developed between the Speed-density for the present condition in the study area.
2. The maximum density was found for the Mahal Road are nearly 162 vehicle/Km.
3. A steep negative slope implies speed drops significantly with increasing density, which suggests the road gets congested quickly.
4. The maximum speed was also found out to be on Mahal Road of nearly 32.98Km/hr. The smoother flow on Mahal Road indicates better alignment, lane width, or reduced roadside interruptions.
4. The R square value indicates the good relationship between observed speed and density for all the roads considered
5 Similarly R square value indicates the good relationship between density and flow.
6. The developed model can be used for the traffic condition similar to Jaipur city.

As traffic in India is heterogeneous and lane discipline is often not followed, implementing measures such as proper lane markings, enforcement of lane discipline, and public awareness campaigns can reduce traffic friction and improve flow.

4.2 Future Scope of Study

1. **Enhanced Data Collection Techniques**: We can employ advanced technologies like IoT sensors, drones, and AI-driven cameras for real-time, precise data collection on traffic flow, volume, and density.
2. **Predictive Analytics and Modelling**: Can develop sophisticated predictive models to forecast traffic conditions and congestion based on historical data, real-time inputs, and varying traffic scenarios.

3. **Adaptive Traffic Management Systems**: Implement smart traffic management systems that adapt to real-time traffic conditions, optimizing traffic signal timings and dynamically adjusting traffic flow to reduce congestion.
4. **Sustainable Traffic Solutions**: Explore and promote eco-friendly transportation methods, such as carpooling, improved public transportation, and cycling infrastructure, to alleviate traffic congestion and reduce environmental impact.
5. **Multimodal Traffic Analysis**: Investigate the interaction between different modes of transport (e.g., cars, buses, bicycles) to develop strategies that optimize the use of existing road infrastructure and reduce congestion.

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