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Research Article

A Study On Traffic Flow Characteristics For Four Lane Divided Highways In India

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ABSTRACT

The current study aims to find the capacity using traffic speed and volume on a multi-lane highway located in north Bihar. The present study analyzes three NH sections (North Bihar Region) having similar features but varying roadway and traffic conditions. The purpose of the study was to find the traffic flow, stream speed variation, and determine the capacity on such a highway where a higher level of heterogeneity (heavy vehicle range between 24-40%) occurs. There have been very few studies on such types of traffic conditions. Videography technique was used to collect traffic flow data. Using that data, stream speed for 5-minute intervals were determined. Fundamental equations were used for all calculations. It was found to be between 2700-3000 veh/hr/dir, which was low compared to HCM and Indo-HCM standards. The effect of heavy vehicles and shoulder width was also observed in this study. Finally, this study provides insight into traffic capacity on such highways, especially four-lane divided highways in Bihar.

Keywords: traffic speed, traffic volume, Fundamental Equations, multilane highways, heavy vehicles, traffic composition

Introduction

Highways with four or more lanes form the backbone of road transportation in major developing economies like India. Built to connect key metropolitan cities and production centers, they handle a significant chunk of passenger and freight traffic. However, exponential rise in vehicular population has led to saturation on several critical links around urban agglomerations and between major economic clusters. This has resulted in chronic congestion, drop in speeds, increased travel times and disruption in supply chains. With further economic growth and improving affordability, vehicular demand is projected to increase manifold over the next decade. There is thus an urgent need to analyse traffic flow behavior and capacity utilization on existing multi-lane highways. For this, understanding of traffic flow characteristics is an important factor.

Multi-lane highways in India have to handle complex heterogeneous traffic comprising vehicles with widely varying static and dynamic characteristics. This includes cars, buses, trucks, light commercial vehicles, tractors, three-wheelers, two-wheelers, cycles and animal drawn carts. The variability in acceleration capabilities, maneuverability, speeds, size and power/weight ratio gives rise to complex interactions. (Chandra and Sikdar, 2000) used micro-simulation to demonstrate the turbulence arising from vehicles crisscrossing multiple lanes during overtaking. Field studies by (Arasan and Koshy, 2005) through video graphic techniques have shown cars and motorcycles changing lanes frequently to maintain desired speeds. The phenomenon of leapfrogging or passing dynamics also comes into play with faster cars slowing down behind heavy vehicles and again overtaking after the blockade is cleared. All this leads to shuffling of vehicles between lanes. Thus, the traffic stream exhibits greater lateral turbulence compared to disciplined lane-based movement.

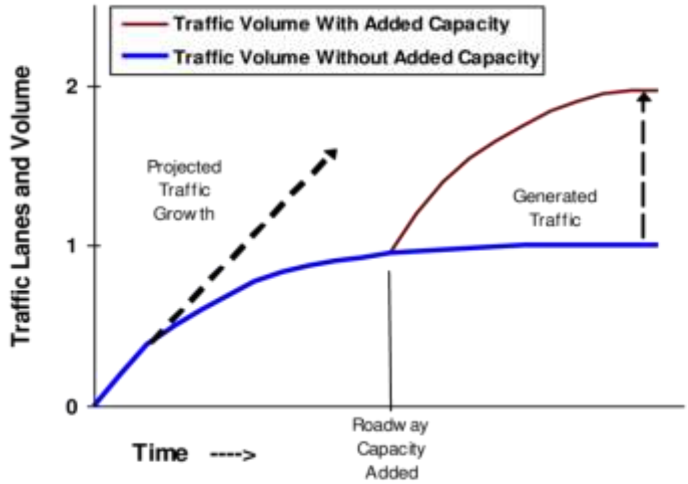


Fig. 1. Road Capacity Expansion Generates Traffic (Litman,2004)

Analysis of volume count data indicates that traffic distribution across lanes is not uniform with the inner lanes carrying higher flows. However, there is lack of detailed observational studies on distribution of traffic across individual lanes under mixed conditions. (Mehar et al., 2013) developed fundamental diagrams for multi-lane divided urban roads in Delhi showing lower jam densities compared to HCM models. The speed-flow curves exhibited drops in average speeds at relatively low flows rates due to heterogeneous conditions. (Chandra et al., 2015) also indicated capacity drop up to 30% during transitions from free flow to congested states. Thus, unique relationships exist between speed, flow, density and composition under mixed traffic.

Capacity Analysis Methods

Being originally developed for homogeneous conditions, conventional methodologies like the Highway Capacity Manual require adaptation for Indian traffic. IRC 106-1990 provides certain modifications like lower free flow speeds, higher Passenger Car Units (PCU) for large vehicles and lower saturation flow rates. However, its application is largely limited to urban roads. There is lack of India-specific capacity analysis techniques for multi-lane divided highways.

(Chandra and Kumar, 2003) proposed a methodology for estimating highway capacity under mixed traffic by measuring prevailing speeds and density. Capacity gets limited by the top operating speed attainable under heterogeneous conditions. Field delays, speeds and density data were used to arrive at capacity values 15-50% lower than IRC estimates.

(Rao and Rao, 2012) suggested an adaptation of HCM principles for divided highways by considering narrower lanes, lower saturation flow rates and higher PCUs typical of Indian conditions. The optimal density range for maximum throughput was lower compared to HCM. A case study on the Mumbai-Pune highway gave capacities around 30% lower than conventional four-lane values. Simulation techniques have also been used to model heterogeneous traffic behavior for better capacity estimation. (Lakshmana et al.,2015) applied tools like AIMSUN and VISSIM to model vehicle interactions across lanes and gaps. Detailed calibration was done based on observed traffic parameters. The models provided insights into disturbances arising from lane changes and its impact on capacity utilization.

Factors Affecting Capacity

Review of empirical studies and direct field observations on Indian highway segments brings out several factors which impact capacity utilization under heterogeneous conditions. These are:

- Lane Width: Narrower lanes constrain vehicle movement and reduce capacity compared to standard 3.5 m width. Observation of vehicle trajectories shows greater lateral variation requiring wider lanes. However, land constraints limit providing more than 3.5m on many highways.
- Traffic Composition: Capacity comes down with higher percentage of heavy vehicles due to lower speeds and longer follower headways. Vehicular interactions also increase with greater diversity in traffic mix. Slow vehicles block faster traffic in the same lane.
- Speed Differentials: Wider speed variance induces frequent overtaking maneuvers. This causes greater turbulence and lane changes affecting steady traffic movement. Segregation of slow and fast traffic can yield capacity benefits.
- Driver Population: Experienced drivers can handle heterogeneous conditions more efficiently. Capacity improves closer to urban areas.

Thus, capacity under mixed Indian conditions is a dynamic outcome of the prevailing operational environment and driver capabilities. Detailed observational data to quantify these impacts is lacking at link and lane levels.

A variety of recommendations have been provided based on research studies for improving capacity on multi-lane highways:

- Lane based Segregation: Separate lanes for buses, trucks and slow vehicles to reduce interaction between vehicles with very different speeds.
- Access Control: Provision of service roads, banning U-turns and direct property access. Reduces points of conflict along the main carriageway.
- Additional Lanes: Widening to 8-lane configuration on very dense routes. Can also implement reversible lane operations during peak hours.
- Improved Lane Discipline: Stringent enforcement, increased fines and public awareness to follow lane-driving principles.
- Traffic Management: Ramp metering at entry points, variable speed limits, highway patrol and CCTV monitoring for swift response to incidents.

Beyond infrastructure measures, attitudinal change among drivers is required through safety awareness and strict policing for optimizing capacity benefits. Advanced traffic simulation can also support evaluation of complex traffic scenarios.

Methodology

This study focused on three roadways similar features but varying roadway and traffic characteristics were selected for this study. A thorough reconnaissance survey was conducted to identify midblock sections devoid of gradients, side friction, direct access, potholes, pedestrian activity, and other factors that could disrupt traffic flow. The key features of these roadways include: (1) each lane being 3.5 meters wide; (2) provision of a hard shoulder in both directions of travel; and (3) separation of traffic flow in both directions by a median. Following the selection of study sections, video cameras were strategically installed at vantage points along the designated locations to ensure clear and continuous capture of traffic flow. Surveys were carried out on a sunny day in March for both sections.

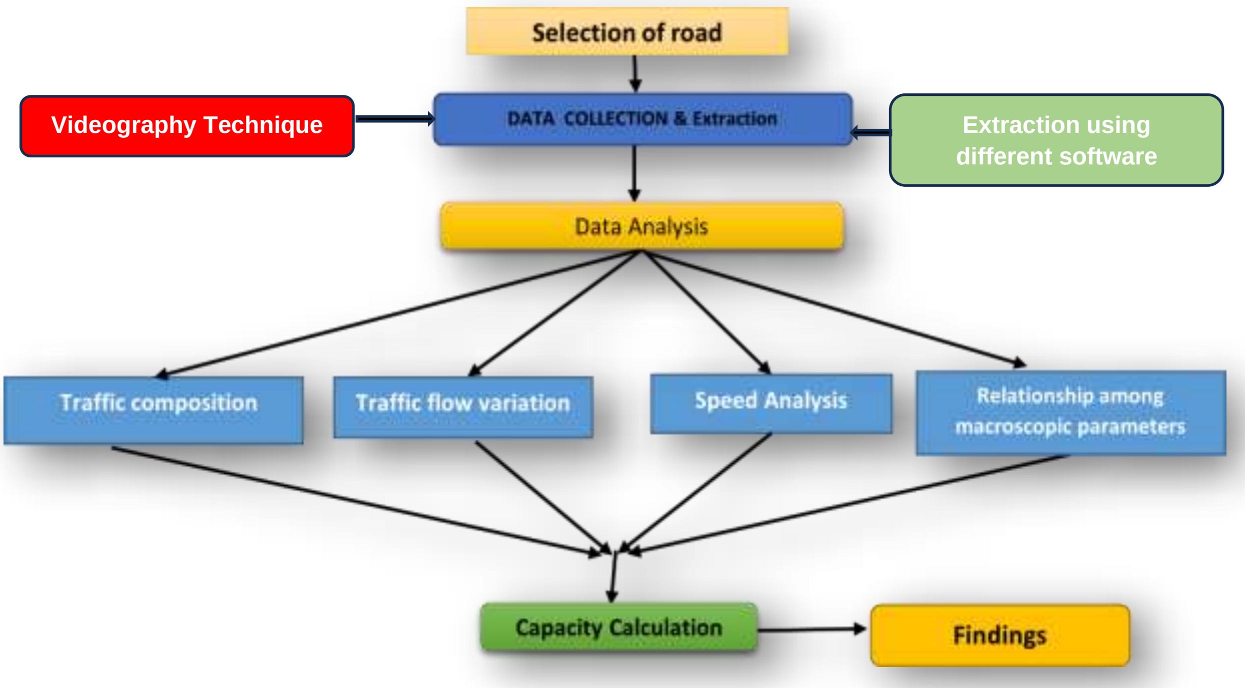
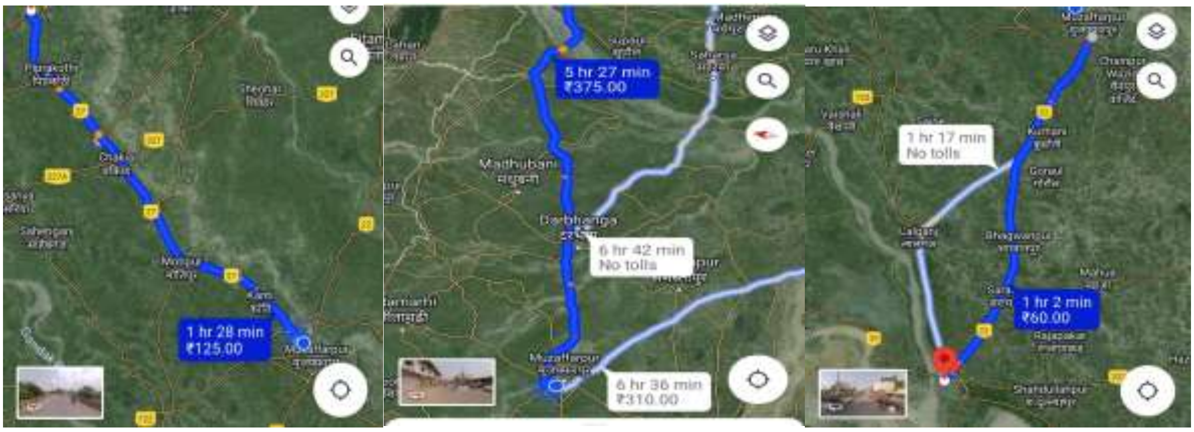


Fig. 2. Flow chart of the study methodology

Data collection

For the study's requirements, data were collected from different sections of three National Highways in north Bihar region. These include NH 27 connecting Muzaffarpur to Lucknow; NH 22 linking Muzaffarpur to Hajipur; and NH 57 leading from Muzaffarpur to Purnia. Each of these sections have four-lane divided carriageway, with a consistent carriageway width of 7 meters each direction and varying paved shoulders measuring 2.4 meters, 0.7-meter, 2.5 meter each side on NH 27, NH 57, NH 22 respectively. To gather traffic data, a designated 60-meter stretch on each highway were marked. The chosen sections experience smooth traffic flow, free from nearby intersections or road features like gradients, ensuring ideal conditions for data collection. Analysis of the gathered data revealed the presence of diverse traffic compositions across all three highways, along with lack of lane discipline. To accommodate varying traffic conditions, such as peak and moderate flows, data collection was undertaken during three-time durations: 7 am to 10 am, 11 am to 2 pm, and 3 pm to 6 pm on each road individually. Furthermore, below are three google map images showing the study areas.



NH 27 NH 57 NH 22

Fig. 3. Google map showing different study section

For data collection purposes, a video camera was installed at a height of 3.6 meters from the ground, strategically install to capture the entire length of the trap without any vehicles overlapping.

Table 1: data collection details on study section

Number	Location	Duration	Date of survey
1	NH 27 (Muzaffarpur to Lucknow)	7 am to 10 am, 11 am to 2 pm, 3 pm to 6 pm (9 Hours)	16 March 2024
2	NH 57 (Muzaffarpur to Purnia)	7 am to 10 am, 11 am to 2 pm, 3 pm to 6 pm (9 Hours)	18 March 2024
3	NH 22 (Muzaffarpur to Hajipur)	7 am to 10 am, 11 am to 2 pm, 3 pm to 6 pm (9 Hours)	20 March 2024

(a)

(b)

(c)

Fig. 4. (a) NH 22 study location section (b) NH 27 study location section (c) NH 57 study location section (d) (; [(a), (b), (c) image by author]

Data Extraction

Micro-level traffic data were extracted from the recorded traffic video using Avidemux 2.8.1 software, known for its precision in displaying time down to one-hundredth of a second. Time stamps indicating the entry and exit of vehicles were manually entered into a Microsoft Excel sheet. Along with Avidmux software. The videos were played multiple times at regular speed, particularly around the moments when vehicles crossed the reference point. This allowed for verbal recordings to be captured and cross-checked for accuracy. Data extracted from the video recordings was organized into tabulated formats, representing in-time and out-time values ranging from 0 to 3600(hourly), measured in seconds. and speeds for vehicles in each direction were then calculated based on these time values. The hourly volume of vehicles traveling towards Motihari, Purnea and Hajipur was determined to be approximately 1650 vehicles per hour, 1512 vehicles per hour and 1738 vehicles per hour, respectively. This data was then utilized for estimating the density using fundamental equation of traffic flow.

$Q = K*V$ (1)

Using calculated traffic density and stream speed data, capacity of all three-road section was estimated using fundamental equation of Greenshield model as

$C = V_{sf} * K_j/4$ (2)

(a)

(b)

(c)

Fig. 5. (a) data extraction of NH 27 (b) data extraction of NH 57 (c) data extraction of NH 22

Result Analysis & discussion

Based on the observed data, it is evident that the traffic composition is predominantly comprised of motorized 2-wheelers and cars. The percentage of 2-wheelers ranges between 15% to 35% across all three sections, with NH 27 and NH 57 exhibiting a similar trend, while NH 22 demonstrates a lower count of 2-wheelers. Autos constitute between 4% to 12% of the composition on these highways. Cars exert a greater influence on traffic composition, fluctuating between 20% to 35%. When considering LCVs, HCVs, and buses collectively as heavy vehicles, their composition surpasses that of all other vehicle classes, spanning from 25% to 40%. The composition of various vehicle classes across different road sections is detailed in the table below. Additionally, graphical representations of morning, afternoon, and evening traffic compositions are provided.

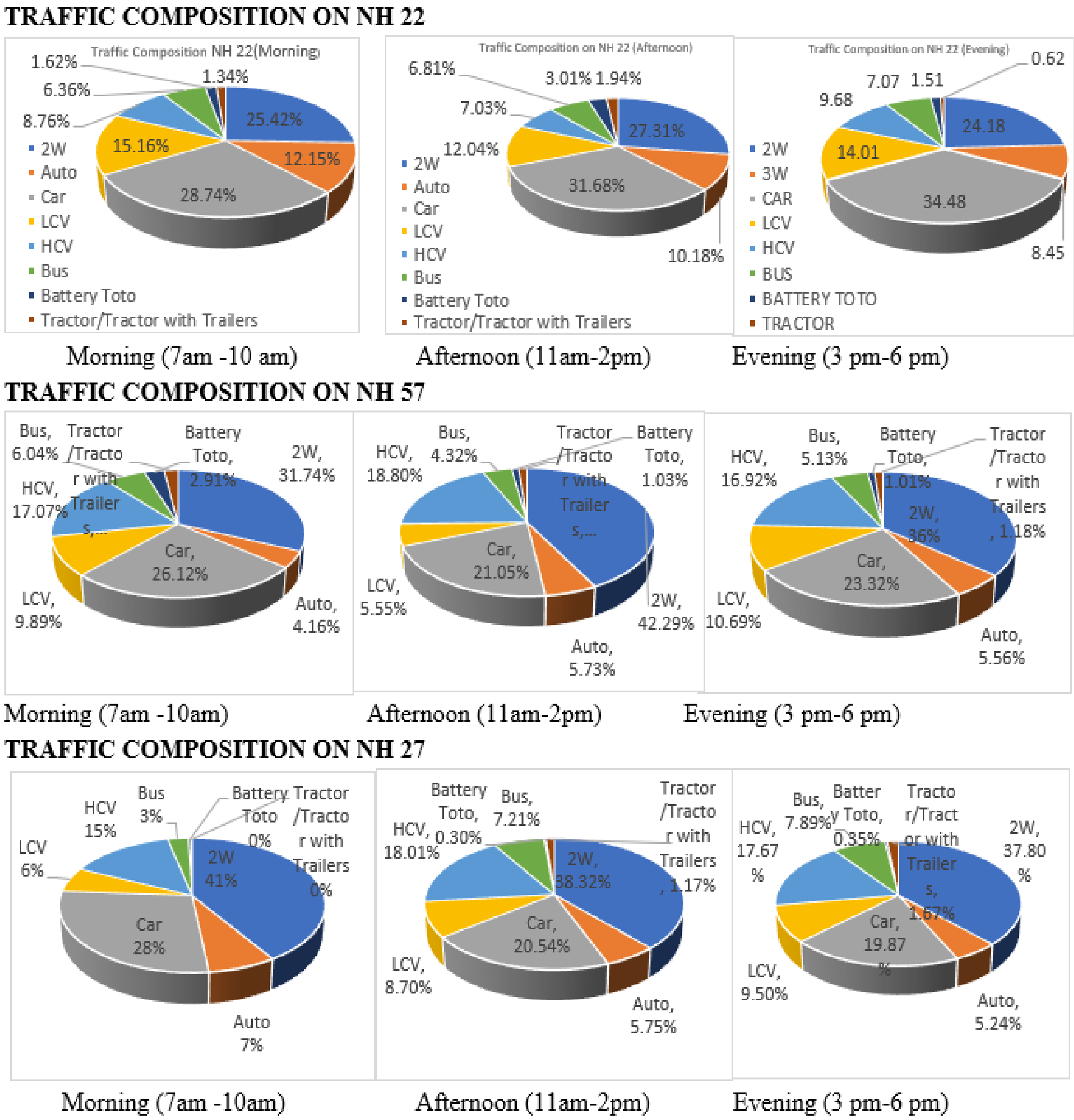


Fig. 6. Pie chart showing traffic composition on NH 27, NH 57, NH 22

Table 2. Traffic Composition for different class of vehicle on NH 27, 57 & 22

Vehicle Category	Traffic Composition Range (based on 5 min interval data)		
	NH 27	NH 57	NH 22
2-wheeler	25-35%	25-35%	15-25%
Auto	5-10%	4-6%	8-12%
Car	20-30%	25-30%	28-35%
LCV	5-10%	6-12%	12-18%
HCV	14-20%	16-22%	7-12%
BUS	4-8%	4-7%	6-8%
Battery toto	0-1%	1-2%	1-3%
Tractor/Tractor with trailor	1-2%	1-2%	1-2%

Stream Speed Analysis

The video camera was positioned on an adjustable stand to ensure it adequately captured the entire length of the trap, with sufficient margin on either side. Subsequently, the desired data, including vehicle entry and exit times, was extracted from the recorded footage in the laboratory using computer software. Each vehicle's time to traverse the trap length was precisely measured with an accuracy of 0.01 seconds, facilitated by Avidemux 2.8.1 software. Figure 4 depicts the meticulous data extraction process, guaranteeing the desired level of accuracy. The time taken by vehicles to cover the trap was then utilized to determine their spot speed, while the traffic volume for each road section was derived from the recorded footage.

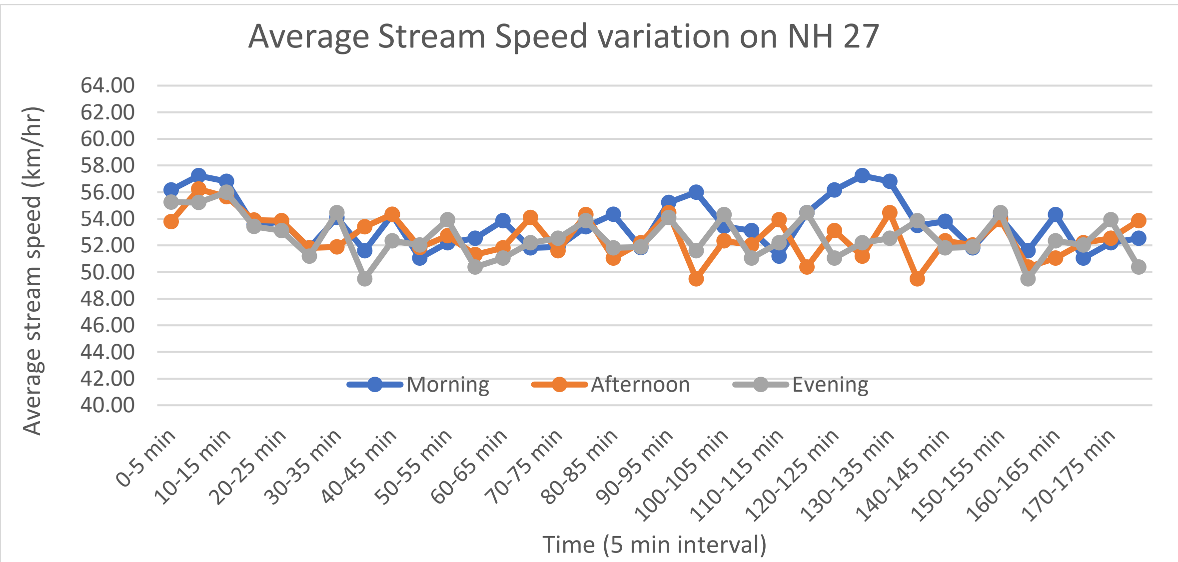
Average speed and maximum speed observed on different roadway section with different sample size are tabulated below.

Table 3. stream speed data for all three NH showing sample size, average speed & Maximum speed;

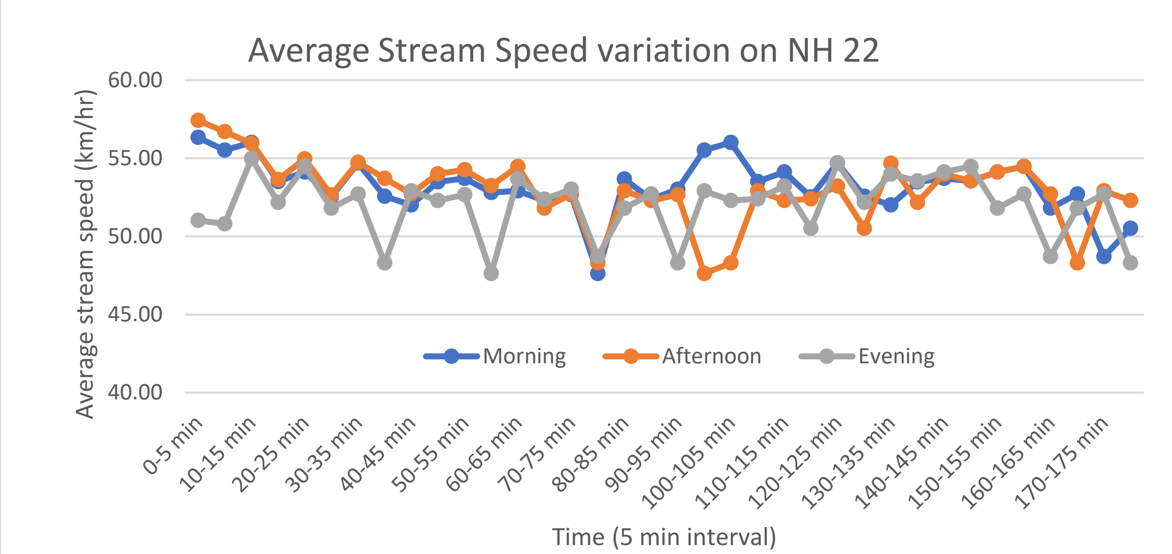
Stream Speed statics of all types of vehicles on different test section				
Section	**Vehicle Type**	**Sample Size**	**Average Speed**	**Max. speed**
NH 27 (Toward Lucknow)	2-wheeler	102	51.7	84.7
	Auto	72	43.6	55.6
	Car	267	71.9	101.9
	LCV	76	48.76	69.8
	HCV	51	45.9	69.4
	BUS	55	62.6	78.5
	Battery toto	22	23.65	44.5
	Tractor/Tractor with trailor	25	38.7	50.5
NH 57 (Toward Darbhanga)	2-wheeler	87	46.8	80.4
	Auto	67	42.7	55.7
	Car	245	73.5	98.6
	LCV	56	51.75	67.9
	HCV	61	47.9	65.7
	BUS	45	61.8	75.67
	Battery toto	27	21.43	40.7
	Tractor/Tractor with trailor	20	38.7	47.4
NH 22 (Toward Hajipur)	2-wheeler	98	46.8	85.6
	Auto	81	42.7	58.9
	Car	255	73.5	104.7
	LCV	65	51.75	72.6
	HCV	45	47.9	71.5
	BUS	60	61.8	80.45
	Battery toto	25	21.43	42.3
	Tractor/Tractor with trailor	23	38.7	48.6

Furthermore, data collected for the average stream speed for each 5-minute interval is plotted for morning, afternoon, and evening durations, and variations are noted down. The plot for the variation of stream speed with a 5-minute time interval is given below.

Variation of stream speed on different NH Section



(a)



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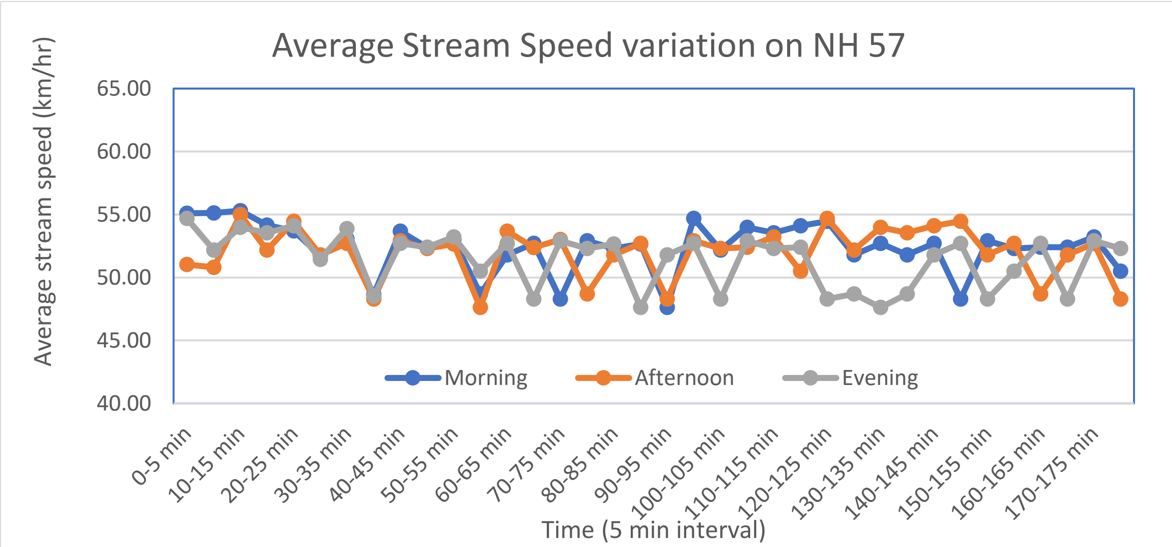
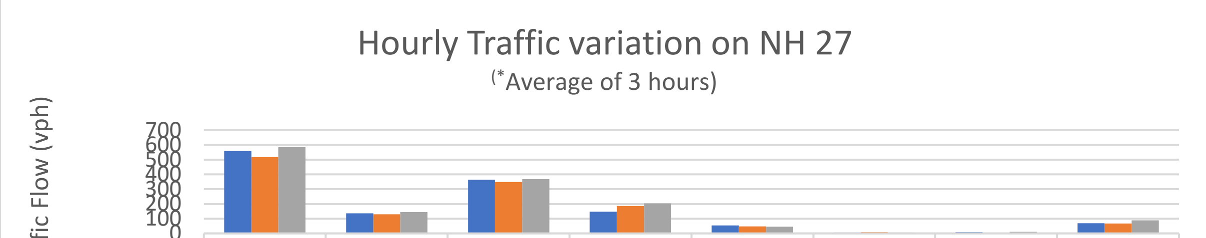


(c)

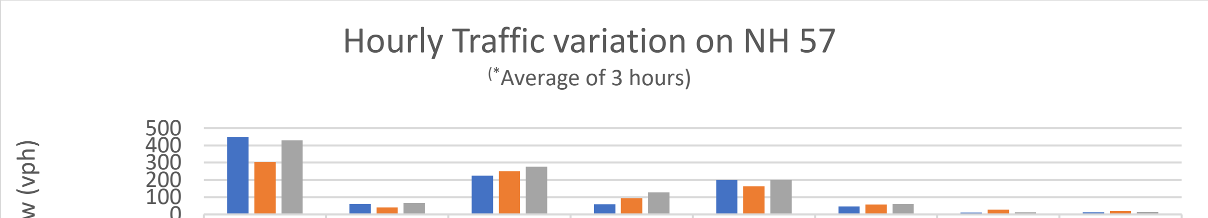
Fig. 7. Variation of stream speed on (a) NH 27, (b) NH 57, (c) NH 22 during morning, afternoon, evening
The speed for a 5-minute duration for each class of vehicle was determined by using entry and exit times on 60 m stretches on each highway. From that data, it was observed that on NH 27, the average stream speed variation lies between 48-58 km/hr. It was also observed that, most of the time, the morning stream speed exceeds that of the evening and afternoon durations. Although these variations lie between 2% to 8%, as shown in fig. 7 (a)Additionally, the stream speed was maximum during the morning session and minimum during the evening session. Similar trends were observed on NH 57 and NH 22, but the average stream speed variation lies between 46-55 km/hr and 46-57 km/hr on NH 57 and NH 22, respectively.

Hourly Traffic Variation



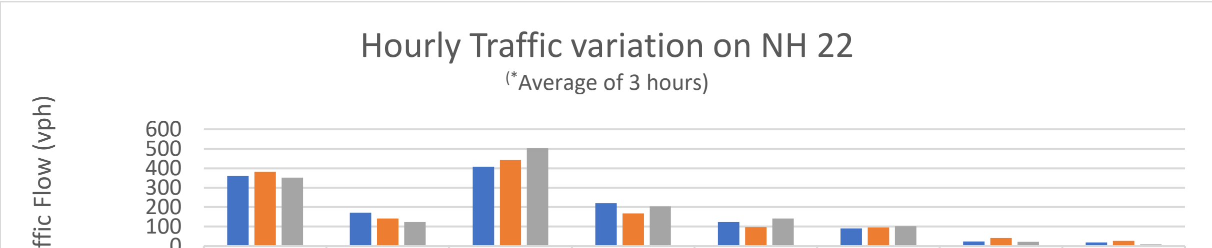
	2W	Auto	Car	HCV	Bus	Battery Toto	Tractor	LCV
MORNING	559	137	363	147	54	6	8	69
AFTERNOON	518	130	349	186	47	8	5	68
EVENING	585	145	368	204	45	7	11	89

(1)



	2W	Auto	Car	LCV	HCV	Bus	Battery Toto	Tractor
MORNING	450	61	224	59	200	46	11	13
AFTERNOON	305	40	251	95	164	58	28	20
EVENING	430	66	277	127	201	61	12	14

(2)



	2W	3W	CAR	LCV	HCV	BUS	BATTERY TOTO	TRACTOR
MORNING	360	172	407	221	124	90	23	19
AFTERNOON	381	142	442	168	98	95	42	27
EVENING	352	123	502	204	141	103	22	9

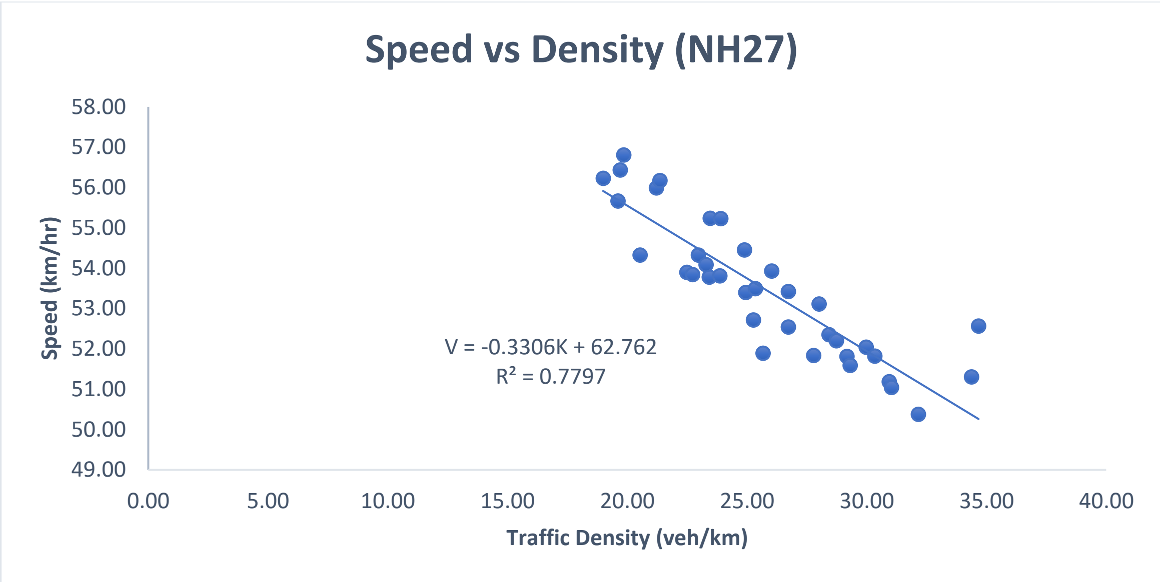
(c)

Fig. 8. Showing Average hourly traffic variation on (1) NH 27, (2) NH 57, (3) NH 22 during morning, afternoon, evening

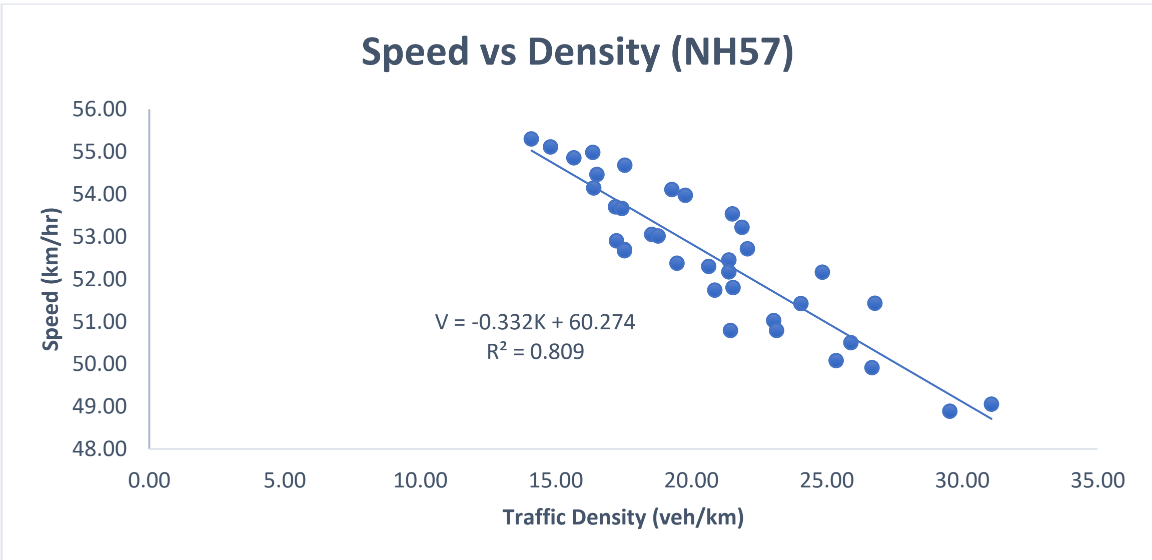
On NH 27, it was observed that during the evening session, the traffic count was at its maximum, except for buses and totos. In the morning session, the traffic count was slightly higher compared to the afternoon session, except for buses and totos. Also, On NH 57, the count of 2-wheelers was higher during the morning session, whereas other classes of vehicles such as autos, cars, LCVs, HCVs, buses, and tractors had their maximum traffic count observed in the evening session. During the afternoon session, the count of cars and buses was higher compared to the morning session. Overall, it was observed that on this highway, the traffic count was highest during the evening session except for totos. Whereas on NH 22, during the afternoon session, the traffic count of 2-wheelers, totos, and tractors was observed to be the highest compared to the morning and evening sessions. Whereas the traffic of cars, LCVs, HCVs, and buses was maximum in the evening. During the morning, the count of autos was the highest. Overall, we can conclude that during the evening, the traffic of cars and heavy vehicles (LCVs, HCVs, and buses) was maximum.

Capacity calculation

After getting speed and traffic flow data, with the help of fundamental equation (1), traffic density calculated. After finding traffic density and speed data for each road section, it is plotted using Greenshield model and finding the general equation for each NH section. Using that equation, capacity also estimated for each road section. Graph for each section is plotted as;



(1)



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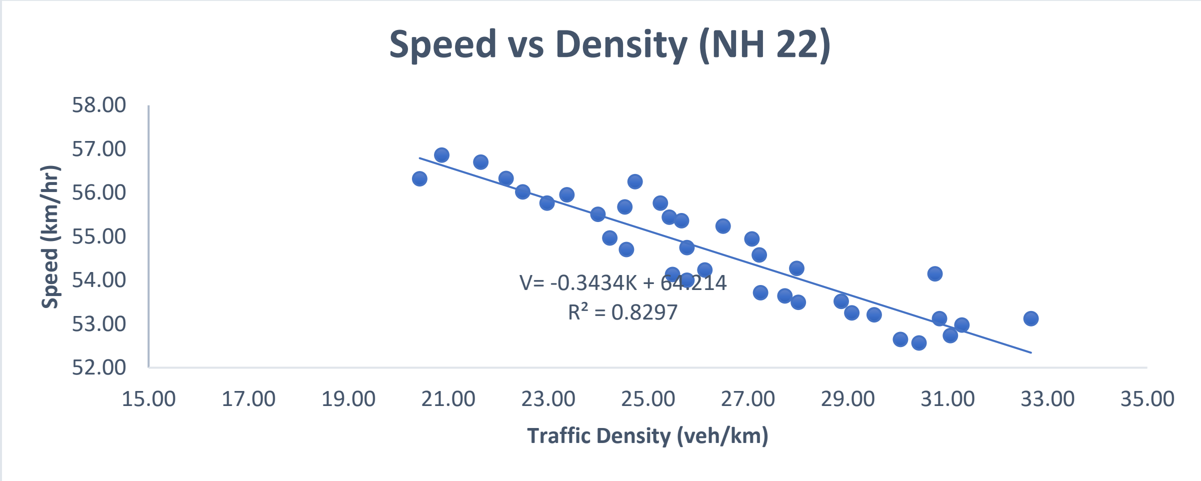


(3)

Fig.9. showing Speed density relationship (linear model) on different NH section

The variation of speed with density is formulated as shown in Fig. 13.1

$V = 62.762 – 0.3306K$ (3)

$R^2 = 0.7797$

Using that relation, the free flow speed (V_f) and jam density (K_j) for NH 27 were calculated as 62.762 km/hr and 189.84 veh/km, respectively. Using that data in equation 2, the capacity for NH 27 was calculated as 2979 veh/hr.

Again, the variation of speed with density for NH 57 is formulated as shown in Fig. 13.2

$V = 60.274 – 0.332K$ (4)

$R^2 = 0.809$

Using equation 4, the free flow speed (V_f) and jam density (K_j) for NH 57 were calculated as 60.274 km/hr and 181.55 veh/km, respectively. Using that data in equation 2, the capacity for NH 57 was calculated as 2736 veh/hr.

Similarly, the variation of speed with density for NH 22 is formulated as shown in Fig. 15.

$V = 64.214 – 0.3434K$ (5)

$R^2 = 0.8297$

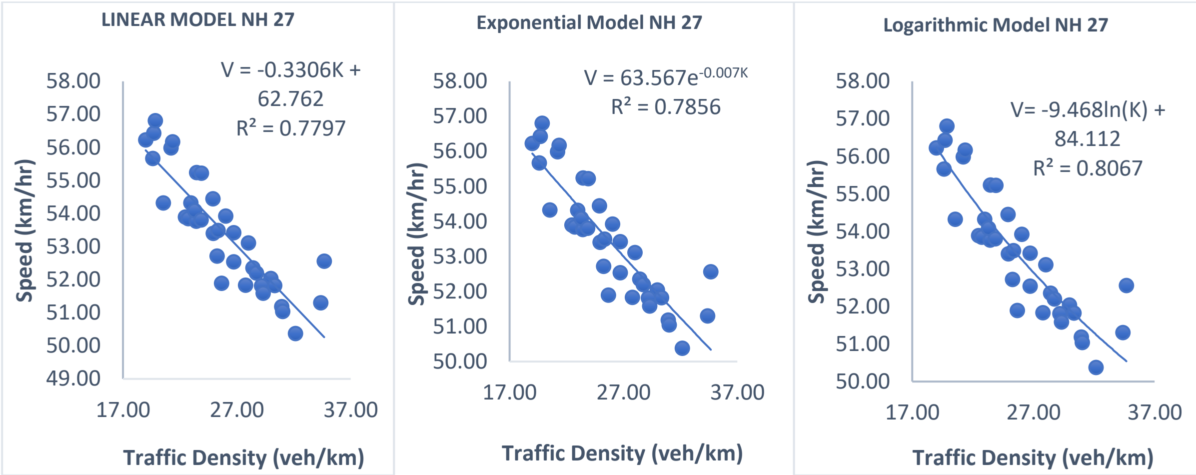
Using equation 4, the free flow speed (V_f) and jam density (K_j) for NH 22 were calculated as 64.214 km/hr and 186.995 veh/km, respectively. Using that data in equation 2, the capacity for NH 57 was calculated as 3002 veh/hr.

Table 4. speed density relationship, free flow speed, jam density and capacity of different road section

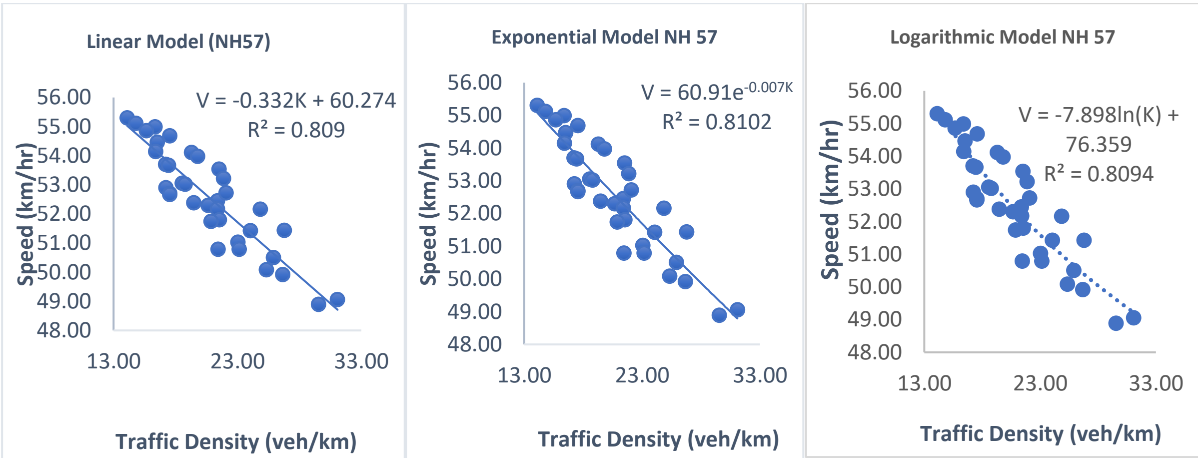
Road Section	Speed density relationship	V_f (km/hr)	K_j (veh/km)	Capacity(veh/hr)
NH 22	$V = 64.214 – 0.3434K$ $R^2 = 0.8297$	64.214	187	3002
NH 27	$V = 62.762 – 0.3306K$ $R^2 = 0.7797$	62.762	189.84	2979
NH 57	$V = 60.274 – 0.332K$ $R^2 = 0.809$	60.274	181.55	2736

After finding capacity on each road section, using same data, plot for linear model, exponential model and logarithmic model is also plotted. Also find their relationship with R^2 value which is tabulated below;

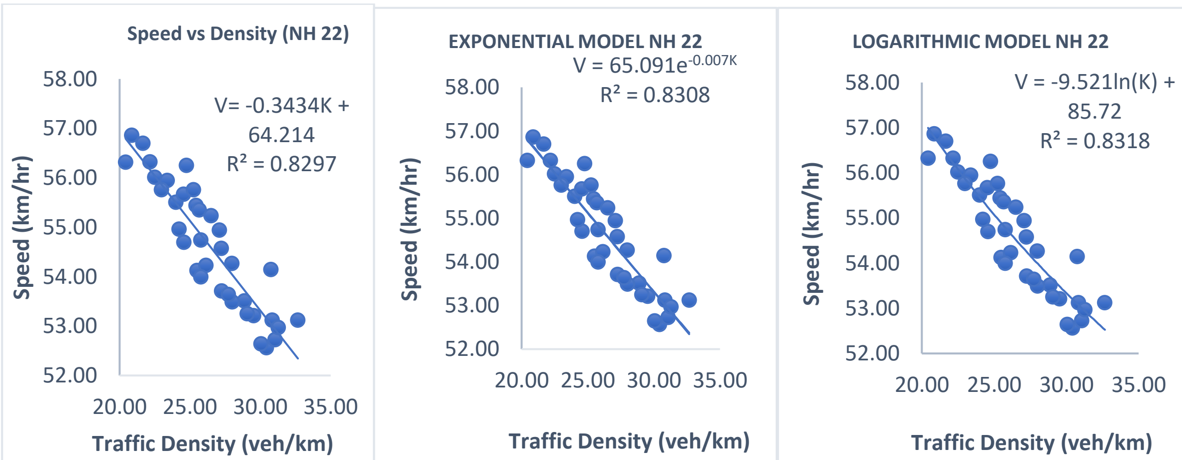
Plot of linear, Exponential Model & Logarithmic model:



a) NH 27



b) NH 57



c) NH 22

Fig. 10. Speed density relationship for Linear, exponential and logarithmic model on a) NH 27, b) NH 57, c) NH 22

Table 5. Linear, exponential and logarithmic model relationship between speed-density

Road Section	Linear model	Exponential model	Logarithmic model
NH 22	V= 64.214 - 0.3434K R^2 = 0.8297	V = $65.091e^{-0.007K}$ R^2 = 0.8308	V = -9.521ln(K) + 85.72 R^2 = 0.8318
NH 27	V = 62.762 - 0.3306K R^2 = 0.7797	V = $63.567e^{-0.007K}$ R^2 = 0.7856	V= -9.468ln(K) + 84.112 R^2 = 0.8067
NH 57	V = 60.274 - 0.332K R^2 = 0.809	V = $60.91e^{-0.007K}$ R^2 = 0.8102	V = -7.898ln(K) + 76.36 R^2 = 0.8094

Conclusion

This study was conducted on four-lane divided highways in North Bihar region (NH 22, NH 27, NH 57). The parameters analysed for the present study are: i) Traffic flow and compositions ii) Stream speed analysis and iii) Relationship between speed and density of traffic stream using different equation. Based on the analysis, following outcomes were obtained:

a) Traffic flow varied between 1500 veh/hr/dir to 1800 veh/hr/dir which is low as compared to HCM.
b) The presence of heavy vehicle (LCVs, HCVs and buses) was observed between 24- 40 %. Which had a great impact on traffic capacity.
c) The effect of shoulder and median conditions significantly affect stream speed, traffic flow, and capacity. It had a great impact on fundamental parameter such as speed, flow and density. It was observed that NH 22 and NH 27 having approximately same capacity due to similar shoulder length and median width. But on NH 57, it reduces by a big margin.
d) It was observed that stream speed was smooth in the morning as compared to afternoon and evening and it lies between 46-58 km/hr.
e) The traffic flow and capacity of NH 22 were maximum among NH 27 and NH 57. Due to the high percentage of heavy vehicles, stream speed, traffic flow, and capacity of these highways are lower compared to Indo-HCM and HCM 2010.

The study conducted here may be useful in analyzing traffic flow on similar four-lane divided highway with higher level of heterogeneity (presence of heavy vehicle in the range of 24-40 %).

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