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Speed Characteristics of Mixed Traffic Flow on Urban Arterials

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***Abstract*—**Speed and traffic volume data are collected on different sections of four lane and six lane roads in three metropolitan cities in India. Speed data are analyzed to fit the statistical distribution to individual vehicle speed data and all vehicles speed data. It is noted that speed data of individual vehicle generally follows a normal distribution but speed data of all vehicle combined at a section of urban road may or may not follow the normal distribution depending upon the composition of traffic stream. A new term Speed Spread Ratio (SSR) is introduced in this paper which is the ratio of difference in 85th and 50th percentile speed to the difference in 50th and 15th percentile speed. If SSR is unity then speed data are truly normally distributed. It is noted that on six lane urban roads, speed data follow a normal distribution only when SSR is in the range of 0.86 – 1.11. The range of SSR is validated on four lane roads also.

***Keywords*—**Normal distribution, percentile speed, speed spread ratio, traffic volume.

I. Introduction

An understanding of traffic speed characteristics is important requirement in the field of traffic engineering. Speed indicates the quality of service experienced by the traffic stream. The knowledge of speed is an essential component of traffic engineering projects related to geometric design of roads, regulation and control of traffic operations, accident analysis, before-and–after studies of road improvement schemes, assessing journey times, congestion on roads and in correlating capacity with speeds. It is one of the components of the fundamental relationships of traffic flow theory other than density and volume. The speeds of individual vehicles have to be specified in the form of a suitable mathematical model for predicting the speed of next vehicle in case of simulation run. Therefore, traffic analysts are required to be familiar with speed characteristics of a road for developing the simulation programs.

Speed data of a traffic stream generally follow the normal distribution when traffic conditions are more or less homogeneous. It deviates from the normal curve as the traffic becomes heterogeneous. Traffic stream in India and many other developing countries consists of vehicles of different categories including car, bus, truck, motorized two wheelers etc. These vehicles have different maneuverability and speed characteristics. Even within the same category of car, there are more than ten different sizes of car on the road with totally different operating characteristics. Similarly the size of a 3-wheeler (auto rickshaw) is almost same as that of a small car, but its acceleration capability is extremely poor as compared to car. 2-wheelers on the other hand, have excellent maneuverability and acceleration characteristics. All these combinations in a mixed traffic situations makes the traffic movement an extremely complex phenomenon. Average stream speed and deviation of speed of individual vehicle from the average speed are controlled by both traffic mix and traffic volume. In such situations, it will be worthwhile to study the speed distribution under mixed traffic conditions on urban roads and its variation with traffic composition. The present paper demonstrates the effect of traffic composition on normality of speed distribution curve and presents a simple procedure to determine the conditions of normality.

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II. Literature Review

Kadiyali et al. [3] studied free speed behavior of vehicles on a four lane divided highway. The speed distributions of vehicles were observed to follow the normal distribution with co-efficient of variation for car, buses and two wheelers being 0.11, 0.13, and 0.16 respectively. Swaminathan et al. [10] further attempted to develop mathematical equations for predicting speed of different vehicle categories under different conditions of road, traffic volume and composition. Katti and Raghavachari [4] developed speed models based on traffic data collected on sub-urban sections of three cities in India. The average speed of fast vehicles varied from 37.8 kmph to 51.5 kmph and for slow vehicles the variation was observed from 10.75 kmph to 15.83 kmph. Speed dispersion was high for fast vehicles and low for bicycles. Passenger loading and purpose of trips were considered responsible of higher order of coefficient of variation of 0.19 and 0.29 for auto and cycle-rickshaw respectively and a minimum value of 0.084 for bicycles. Speed data for fast moving vehicles followed normal distribution whereas log-normal distribution model defined the speed data for bicycles. Leong [5] and McLean [6] found that, for lightly trafficked two-lane roads where most vehicles are traveling freely, car speeds measured in time are approximately normally distributed with coefficient of variation ranging from about 0.11 to 0.18. Haight and Mosher [2] found that the time speeds could be well represented by either a gamma or a log-normal distribution. These distributions offer the advantage that the same functional form is retained when the time speed distribution is transformed into a space-speed distribution and avoid the theoretical difficulty of the negative speeds given by the infinite tails of the normal distribution. Sahoo et al. [9] also found that the vehicular speeds conform to the normal distribution with a mean of 42–45 km/h and standard deviation of 9–13 km/h on different intercity roads in India. Najjar et al. [7] and developed neural-network-based speed models to establish a relationship between the roadway characteristics and the 85th percentile speed (V_{85}) on Kansas two-lane highways. The model predicted V_{85} with an average degree of accuracy of about 96 percent. Al-Ghamdi [1] analyzed spot speed data on urban roads in Riyadh and found that obtaining the 85th percentile speed from regression modeling gives much better estimates than those from the normal approximation model. Van Aerde and Yagar [11] found that an increase of 1,000 passenger cars/h in the main line traffic reduces the average speeds of the 90th, 50th, and 10th percentile by approximately 8, 5, and 3 km/h, respectively. They also found that an additional 1000 trucks decrease the mainline traffic speed by approximately 30 km/h in Ontario, Canada.

III. Field Data Collection

Data for the present study were collected at 17 different urban arterial roads in three cities of India namely New Delhi, Jaipur and Chandigarh. New Delhi is the county capital with the population more than 16 million whereas Jaipur and Chandigarh are the state capitals and their population is around 6 million and 1 million respectively as per the provisional report of census of India, 2011 [8]. All the study locations were on six lane and four lane divided roads. The basic consideration in selection of a section was that it should be free from the effect of intersection, bus stops, parked vehicles, curvature, gradient, pedestrian movement and any other side friction. Also, the sections should have wide variations in proportions of different categories of vehicles. Traffic studies were carried out to determine the traffic volume, composition of traffic stream, and the speed of different types of vehicles at the selected road sections. The data were collected through video camera at each section on a typical weekday during peak hour time. A longitudinal trap of 50m was made on one side of the carriageway for the measurement of speed. The video camera was mounted on the stand and placed at a vantage point so as to cover the entire length of the trap. The recorded film was replayed in the laboratory to extract the desired information. The vehicles are divided into six categories as shown in Table I. As mentioned earlier also, there are several models of car plying on Indian roads. For the purpose of making the analysis meaningful, cars are also divided into two categories as small and big car. Small car in Table I represents all cars having engine power of 1405cm^3 and length and width of 3.72m and 1.44m respectively. The big car is one having the length of 4.58m, width 1.77m and engine power 2494cm^3.

The average time taken by each vehicle to travel through the trap marked on carriageway was measured with an accuracy of 0.01s using software developed for this purpose. This time was used to calculate the speed of a vehicle passing through the trap. Table I provides the details of traffic composition and traffic volume at different sections.

TABLE I
Observed Traffic Composition at Different Sections

Section Number	Type of Road	Traffic Volume (veh/hr)	Composition (%)					
			Small Car	Big Car	Heavy Vehicle	3-wheeler	2-wheeler	Pedal Cycle
1	Six Lane	4100	38.3	5.10	2.60	20.60	33.40	-
2	Six Lane	3200	51.50	5.96	1.00	13.43	28.11	-
3	Six Lane	3400	54.85	4.85	0.75	10.82	28.73	-
4	Six Lane	4000	28.35	8.66	7.82	17.74	30.45	6.98
5	Six Lane	3600	40.00	4.50	2.60	18.50	32.40	2.00
6	Six Lane	3500	40.12	4.90	7.00	10.08	37.90	-
7	Six Lane	3700	40.00	4.50	2.60	18.50	34.40	-
8	Six Lane	2400	34.18	8.06	3.44	13.75	37.72	2.85
9	Six Lane	5500	46.50	7.55	3.64	12.70	29.61	-
10	Six Lane	2250	31.27	12.59	4.36	20.30	31.47	-
11	Six Lane	5200	46.50	7.10	1.65	16.70	28.00	-
12	Six Lane	3300	25.50	4.50	5.60	22.70	38.70	2.00
13	Six Lane	2300	33.30	12.75	3.23	21.72	29.00	-
14	Six Lane	2700	46.00	8.38	1.32	13.60	30.70	-
15	Six Lane	4000	30.12	5.38	10.35	25.43	28.72	-
16	Four Lane	1700	43.61	15.79	3.11	11.14	26.35	-
17	Four Lane	4000	32.64	14.85	4.77	22.63	25.12	-

IV. Analysis of Speed Data

The vehicular speed data collected for all categories of vehicles at a section were converted into the frequency distribution table of suitable class interval. The class interval is calculated from the following formula:

$$i = \frac{Range}{1+3.222\log N} \quad (1)$$

where:

i = interval class

Range = Maximum – Minimum (speed values)

N = No. of data points.

Mean speed and standard deviation were calculated from these frequency distributions. An attempt was made to fit a normal distribution to individual vehicular speed data and to the speed data of all vehicles combined at each section. The speed distribution curve for all vehicles at section 10 is shown in Fig. 1. This resembles the shape of a normal distribution curve. The computation for normal distribution is shown in Table II. The calculated and critical values of Chi-square were obtained as 4.98 and 14.07 respectively, at 7 degree of freedom and 5 percent level of significance. As the calculated value is less than the tabulated value, the hypothesis that the speed data would not follow a normal distribution is rejected. The speed data curves for small cars and 3-wheelers at this section are shown in Figs. 2 and 3 respectively. Similar curves were plotted for other categories of vehicles also. All these data follows normal distribution. Similar analysis was done at other sections also and it was found that speed of individual type of vehicles can be invariably represented by normal distribution with different means and standard deviations. However, aggregate speed data for all vehicles at a section do not always follow the curve of normality.

TABLE II
Fitting of Normal Distribution to Speed Data at Section 10 (All Vehicles)

S. No.	Speed Interval (kmph)	Observed Frequency (O)	Probability (p)	Expected Frequency (E)	$\chi^2 = (O-E)^2/E$
1	30-35.99	5	0.009	8.78	1.493
2	36-41.99	25	0.032	32.18	1.385
3	42-47.99	85	0.085	83.75	0.019
4	48-53.99	164	0.162	159.94	0.130
5	54-59.99	225	0.222	218.24	0.209
6	60-65.99	200	0.218	214.79	1.019
7	66-71.99	161	0.154	152.80	0.533
8	72-77.99	80	0.079	77.33	0.092
9	78-83.99	29	0.029	28.28	0.018
10	84-89.99	8	} 0.008	7.43	} 0.08
11	90-96	3	} 0.001	1.40	
	Total	**985**	**1.000**	**~ 985.00**	**4.977**

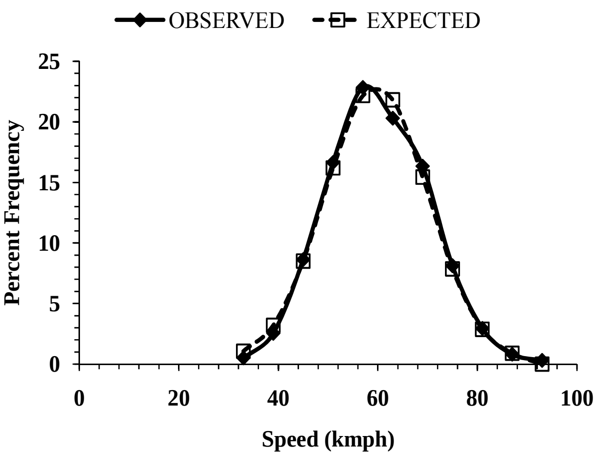

Fig. 1 Observed and expected frequency curves for all vehicles at section 10

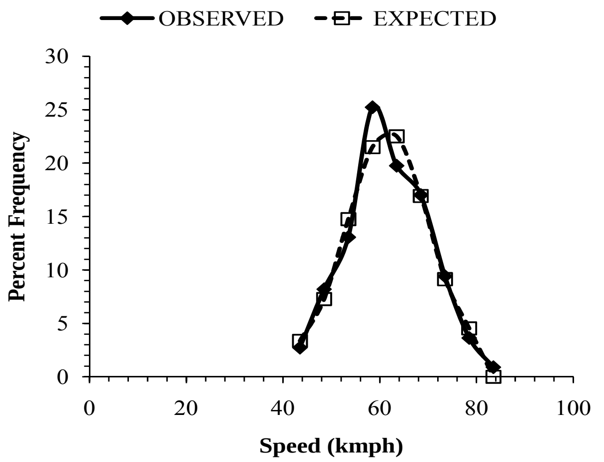

Fig. 2 Observed and expected frequency curves for small cars at section 10

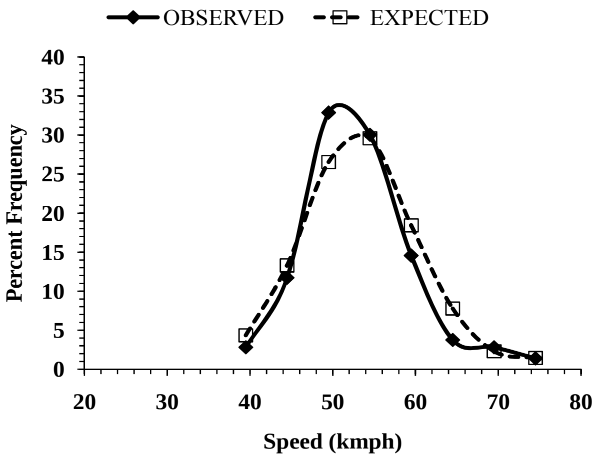

Fig. 3 Observed and expected frequency curves for 3-wheelers at section 10

Frequency distribution of speed data at section 15 for example is shown in Fig. 4. The calculated Chi-square value is 91.93 against the critical value of 7.81 at 5 percent level of significance. Therefore, these data cannot be represented by a normal distribution. It was checked for all the 15 sections of six-lane roads and it was observed that the speed data of total traffic stream were normally distributed at 6 sections only.

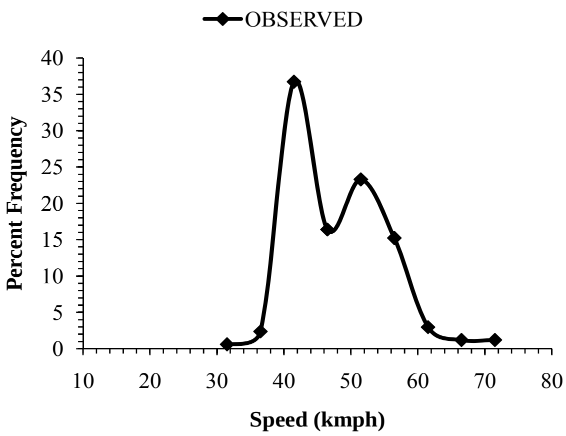

Fig. 4 Observed frequency curves for all vehicles at section 15

The normality of speed data was found to be influenced by the presence of slow moving vehicles (Pedal cycles) also. Even at a very low percentage of these vehicles (2 percent at section 5 and 12, for example), the speed data did not follow the normal distribution. It is due to the very low speed of these vehicles which causes another subdivided peak in the frequency distribution curve in low speed range (around 10 kmph). This peak becomes quite distinct as the proportion of pedal cycles increases in the traffic stream. However, the above explanation does not hold good for section 8 where speed data followed the normal distribution with 2.85 percent pedal cycles in the traffic stream. It suggests that although the proportion of individual vehicle type may be responsible for changes in speed distribution curve on a road, it is the composition of total traffic stream which determines whether or not the speed data will follow a normal distribution curve.

V. Condition of Normality in Speed Data

A normal curve is characterized by its bell shape with equal spread of the data above and below the mean value. Therefore, the normality in speed distribution curve can be better explained by the extent of spread in the speed data from its mean value. A parameter called Speed Spread Ratio (SSR) is introduced in this paper to indicate the spread on left and right side of the mean speed. SSR is defined as the ratio of difference in 85th and 50th percentile speed to the difference in 50th and 15th percentile speed on a section.

$$SSR = \frac{V_{85} - V_{50}}{V_{50} - V_{15}} \qquad (2)$$

V_{15}, V_{50} and V_{85} are the 15th, 50th and 85th percentile speeds at a section respectively. These are explained in Fig. 5. V_{85} and V_{15} are almost one probit distance on the right side and left side of the mean value respectively.

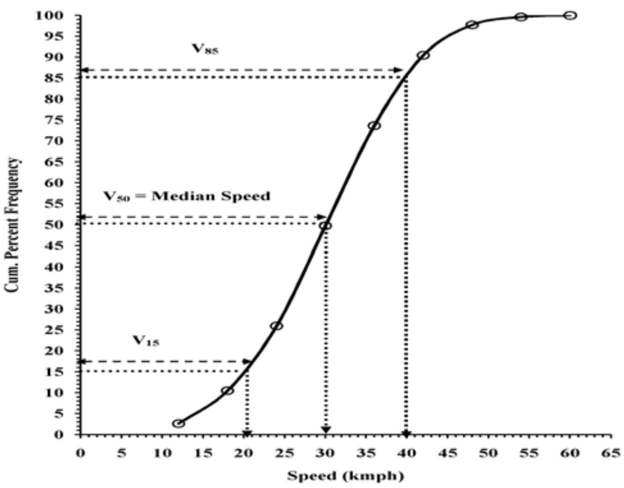

Fig. 5 Determination of Speed Spread Ratio (SSR)

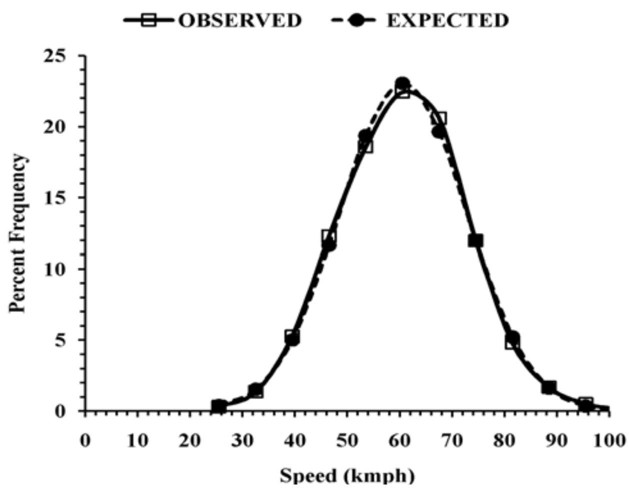

Fig. 6 Observed and expected frequency for all vehicles at section 16

In a truly bell shaped curve these distances will be equal and therefore, SSR will be unity. It will tend to deviate from the normal distribution as the SSR deviates from unity. The values of SSR as calculated at 15 sections of six-lane roads are given in Table III. As may be seen, the speed data follow the normal distribution curve when SSR is within the range of 0.86 – 1.11.

The above range of SSR is calculated for six-lane urban roads. To check the transferability of this range, two sections of four-lane divided roads (section 16 and 17) were also included in this study. The value of SSR for section 16 was 0.98 which is within the range of 0.86 – 1.11 and the data therefore followed the normal distribution as shown in Fig. 6. At section 17, the SSR is 1.13 and data did not fit the normal distribution. Therefore, the range of SSR estimated for six-lane roads is valid for four-lane roads also. The details of section 16 and 17 and their SSR values are tabulated in Table IV.

TABLE III
SPEED SPREAD RATIO (SSR) AT DIFFERENT SECTIONS

Section Number	V_{85}	V_{50}	V_{15}	SSR = $\frac{V_{85}-V_{50}}{V_{50}-V_{15}}$	Normal Distribution
1	56.00	53.15	47.00	0.46	No
2	51.50	57.00	53.50	0.54	No
3	58.00	53.50	47.50	0.75	No
4	50.00	39.00	25.50	0.81	No
5	56.25	48.75	39.75	0.83	No
6	57.00	51.00	44.00	0.86	Yes
7	57.50	51.00	44.00	0.93	Yes
8	40.00	30.25	20.25	0.98	Yes
9	46.00	39.50	33.50	1.08	Yes
10	68.00	56.50	46.00	1.10	Yes
11	55.50	50.50	46.00	1.11	Yes
12	55.50	46.00	38.00	1.19	No
13	67.50	56.00	46.50	1.21	No
14	62.50	54.00	47.50	1.31	No
15	53.00	44.50	38.50	1.42	No

Speed distribution in a traffic stream is greatly influenced by the proportion of slow moving vehicles like heavy vehicles, 3-wheelers and non-motorized vehicles. Proportion of heavy vehicles on all the 17 sections selected in this study varies in a very narrow range of less than 10 percent. Pedal cycles were present only at 4 locations. 3-wheelers on the other hand, were present in all sections and their proportion varied from 10 to 25 percent. Therefore effect of 3-wheelers on speed distribution curve could only be studied here and their presence consequently affects the SSR. Fig. 7 shows the variation in SSR with the varying proportion of 3-wheelers and it is well represented by the polynomial trend with constant term of 0.86, the lower limit of SSR for normal distribution. The physical dimensions of 3-wheelers are more or less similar to the small car, but their operating speed are much lesser then the small car. As the proportion of 3-wheelers increases in the traffic stream a second peak in the speed distribution curve is observed. This peak will be distinct when 3-wheelers in the traffic stream are more than 20 percent. At this composition of traffic stream, SSR will be more than 1.11 and the speed data would not follow the normal curve.

TABLE IV
VALIDATION OF SSR ON FOUR LANE URBAN ROADS

Section No.	Type of Road	Traffic Volume (vph)	V_{85}	V_{50}	V_{15}	SSR = $\frac{V_{85}-V_{50}}{V_{50}-V_{15}}$	Chi-Square	Critical chi-square	Normal Distribution
16	Four Lane	1700	69.75	57.25	44.50	0.98	6.07	15.51	Yes
17	Four Lane	4000	44.25	35.75	28.50	1.13	29.91	16.92	No

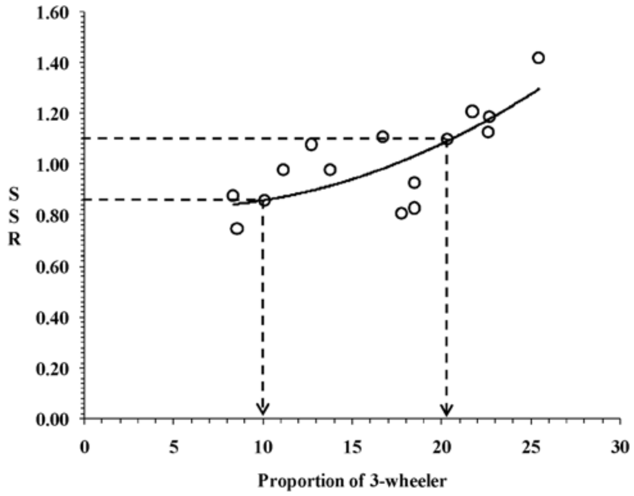

Fig. 7 Variation in SSR with the proportion of 3-wheelers

VI. Effect of City Size on Free Speed

The variation in free speed is analyzed with respect to city size in terms of its population. Free speed of car was determined on six-lane roads in three cities of Chandigarh, Jaipur and New Delhi are plotted against population in Fig. 8 (data in the parenthesis shows population in Million). It is observed that the free speed increases with the size of the city. This may be due to the driving experience of the driver and the better condition of the road surface in a big sized city.

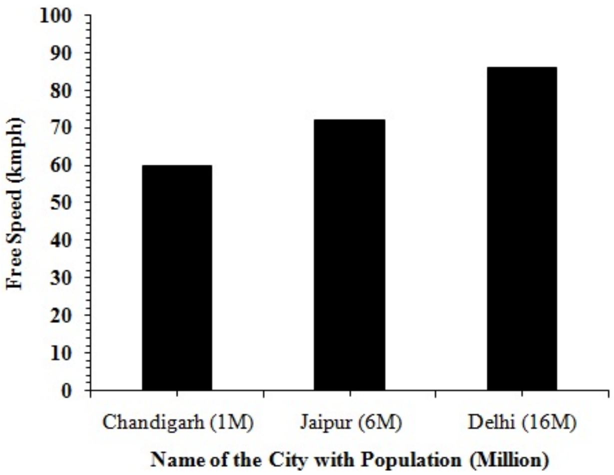

Fig. 8 Variation in free speed of car with respect to the city size

VII. Conclusions

The present study demonstrates the effect of traffic composition on the speed distribution on a section of a multilane divided urban road under mixed traffic conditions. It suggests that speed data may or may not follow the normal distribution depending upon the proportion of relatively slower vehicles like 3-wheelers in the traffic stream. The Speed Spread Ratio (SSR) defined in this paper is a good predictor of normality in the speed data. It is shown in this paper that speed data on an urban road would follow the normal distribution as long as SSR is within the range of 0.86-1.11. Two peaks are observed in the speed data when SSR is either less than 0.86 or more than 1.11. The second peak occurs when proportion of 3-wheelers is more or pedal cycles are present in the traffic stream. Further, the effect of city size on free speed of car is also investigated and it is found that free speeds are higher in large cities. It may be attributed to more driving experience and better road surface conditions in a big city like New Delhi.

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