VEHICLE ARRIVAL, TIME HEADWAY AND SPEED DISTRIBUTIONS UNDER MIXED TRAFFIC CONDITIONS ON MULTILANE HIGHWAYS

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ABSTRACT

Time headway and speed distribution studies provide an insight into the aggregate flow of vehicles which have important applications in capacity estimation, Level of Service analysis, safety analysis, etc. Field data for study was collected using video-graphic method at different mid-block sections of multilane divided highways. Analysis of vehicle arrival, time headway and speed data of vehicles carried out to obtain the distribution patterns in mixed traffic condition. From the results concluded that Poisson distribution is best fit for vehicle arrival data. Pearson6 and Generalized Extreme Value distribution (GEV) is found to be the best fit for headway data. Gamma and Weibull distributions are also found suitable to fit time headway distribution. The results of this paper can find direct applications in developing micro-simulation models.

Keywords: *Highways, speed, time headway, vehicle arrival*

Introduction

Knowledge of distribution of the vehicle arrival pattern or inter-arrival pattern (headways) of vehicles is very essential in order to understand the general traffic flow behavior on multilane highways. The arrival pattern of vehicles at a point (or) line on roadway defines the longitudinal distribution of vehicles in a traffic stream. The distribution of arrival time of vehicles enables the traffic engineers and planners to estimate the availability and magnitude of gaps and headways in traffic stream, which are the direct measure of the density and volume on the highway. Vehicle arrival is also used as an essential input in the simulation of traffic behavior. However, most of the researchers have studied the arrival characteristics of vehicles through headway distributions.

An understanding of traffic speed characteristics is an important requirement in the field of traffic engineering. IRC: 64 (1990) defines speed as the rate of motion of individual vehicles or of a traffic stream measured in meters per second (m/s), or more generally in kilometres per hour (km/hr). 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, and 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 speed characteristics of a traffic facility serve as an essential input in simulating the traffic behavior on that facility. Complete knowledge of speed distribution pattern on multilane highways is essential to simulate the traffic flow behavior.

Minh et al. (2005) studied motorcycle behavior in Hanoi city of Vietnam. Authors reported average headway as 1.16s for all four locations and a standard deviation of 0.65s. It was observed that 50% of two-wheelers were found to travel in interval range of 0.5-1.0 s headways. In spite of differences in the geometric parameters, traffic composition and operations, all the four locations were reported to have same mean headway. Xue et al. (2009) analyzed time-headway distributions on expressways in Beijing, Shanghai, and Guangzhou cities, China. It is found that the sections having traffic volume less than 250 vph fits negative exponential distribution to headway data. For traffic volume ranging 250 to 750 vph, data follows a sifted negative exponential distribution. And, for traffic volume ranging 750 to 1,500 vph, the time headways can be modeled with Cowan's M3 distribution model. Lognormal distribution was found to be the best distribution in modeling time headways in a steady state car-following situation as suggested by Dey and Chandra (2009). Riccardo and Massimiliano (2012) studied the vehicular time headways on two lane two way roads in the Province of Venice and found that Inverse Weibull distribution fitted well for most of the flow rates ranges and Log Logistic, Person 5 fitted well for high flow rates. Some mixture models like Weibull + Lognormal (WLN) and Weibull + Extreme value (WEV) were also tried to model time gaps at flows of 2300 veh/h and 1900 veh/h respectively under mixed traffic, Dubey et al. (2013). Panichpapiboon (2014) concluded that GEV distribution is most effective in modelling time headways. However, the exponential distribution was found to be the least effective distribution under heavy traffic volume.

Abraham (2001) analyzed speed data on Ontario highways and recommended increase the speed limit from existing 100 kmph to 110-130 kmph and 105-110 kmph on two different highways respectively. Due to undisciplined driving behaviour, left lane reserved for passing operations was found to be utilized as a regular lane leading to almost same average speeds in both left and middle lanes. Velmurugan et al. (2002) studied the change in operating speed characteristics vehicles on rural highways, based on the outcomes of Road User Cost Study (RUCS) -1982, 1992 and 2001. The comparison of results showed that there was significant increase in speeds of all vehicle categories on roads of different widths between 1982 and 2001 and also between 1982 and 1992. Basic Desired Speed (BDS) on four-lane divided highways with paved shoulders were similar to that on two-lane bi-directional roads with paved shoulders, representing insignificant impact of geographical factors on BDS. Free speed of new technology cars was observed to be 21 to 28 % higher than that of old ones on both two and four lane highways. Dixon et al. (1999a, b), Hastim and Ramli (2013) examined speed in rural multilane highway and found that the distribution of free flow speed was found to be normally distributed. Wang et al. (2012) introduced truncated normal and lognormal distribution for modeling speeds and travel time. Zou (2013) proposed that skew-t distribution can reasonably take into account the heterogeneity in vehicle speed data. It is seen from the background study that for homogeneous traffic situation speed values can be represented by normal distribution but for mixed traffic condition there is variability in observation, also there is not such study which has identified class wise vehicular speed behavior.

Maurya et al. (2016) found that Burr distribution is representing the time headway for all density ranges whereas for speed data, Beta distribution is best fit. Roy and Saha (2018) found that Log-logistic distribution is best fit to represent the moderate traffic whereas Pearson 5 is best fit for congested traffic. Prahara and Prasetya (2018) observed that negative exponential distribution is best fit for time headway of motorcycle. Yogeshwar et al. (2018) found that vehicles having headway of 5-25 s follow the log-normal distribution whereas, headway of 15-40 s follow GEV distribution. Boora et al. (2018) used Gap instead of time headway for mix traffic and found that exponential distribution is best fit. The present paper attempts to study the vehicular arrival, time headway and speed distributions for mixed vehicular flow on multilane highways.

1. Field Investigations And Data Collection

Field data for study was collected at different mid-block sections of multilane divided intercity highways. Location of highways where data was collected are parts of National Highway (NH) exists on plain terrain with straight alignment, some sections are access control and some are partially access controlled in both the directions of travel. Details of the study sections have been given in the Table 1. Section I, Section II and Section III are located on NH 163 near Madikonda village, Bibinagar village and Ghanpur village respectively. However, these sections are differs from the type of access control. Section-I has no access control and Section-II has fully control of access whereas Section-III is partially access controlled. Section IV is NH45A (NH332, as per new numbering) connecting Chennai to Nagapatinam, near Viluppuram district, in Tamilnadu State. Section-Vis a part of NH 58 located in between Delhi and Meerut city near Modinagar. Section VI is located on NH24 connecting Delhi and Harpur cities.Section-VII and Section-XI are located on NH 16 between Guntur and Ongole cities respectively, which is a six-lane divided intercity highway having 1.8 m paved shoulders. Section-VIII is selected from NH 8 near Delhi, which is an eight-lane divided intercity highway having 1.8 m paved shoulders. Field data were extracted manually from the video recording playing videos on big screen monitor in traffic engineering laboratory.

Table 1. Details of the study sections

Sections	Highway No.	Location	Type of highway	Type of Shoulder	Properties	Posted speed limit (Kmph)
I	NH 163	Near Madikonda (Telangana)	Four lane Divided	Paved	CW: 7.0 SW: 1.5	80
II	NH 163	Near Bibinagar (Telangana)	Four lane Divided	Paved	CW: 7.0 SW: 1.5	80
III	NH 163	Near Ghanpur (Telangana)	Four lane Divided	Paved	CW: 7.0 SW: 1.5	80
IV	NH 332	Near Vilupparam (Tamilnadu)	Four lane Divided	Paved	CW: 7.0 SW: 1.5	80
V	NH 58	Meerut (Uttar Pradesh)	Four lane Divided	Un paved	CW: 7.0	80
VI	NH 24	Delhi-Hapur (Uttar Pradesh)	Four lane Divided	Unpaved	CW: 7.0	80
VII	NH 16	Near Guntur (Andhra Pradesh)	Six lane Divided	Paved	CW: 10.5 SW: 1.8	90
VIII	NH 8	Delhi-Gurgaon (Delhi)	Eight lane Divided	Paved	CW: 14.0 SW: 1.8	120
IX	NH 16	Ongole (Andhra Pradesh)	Six lane Divided	Paved	CW: 10.5 SW: 1.8	90

*CW-Carriageway width (in meters), SW-Shoulder width (in meters)

2. Vehicle Arrival Characteristics

Poisson distribution is considered to be an appropriate distribution for describing random occurrence of discrete events like arrival pattern of vehicles. However, it was observed that mean and variance are not equal in all the cases and hence Poisson does not always give a good fit for vehicle arrival pattern. In these cases, negative binomial distribution may be more suitable.

2.1. Analysis of Vehicle Arrival Pattern

Vehicle arrival data collected at two different mid-block sections of multilane highway was extracted in the laboratory. Time interval of extraction of data was chosen as 20s. The frequency tables were prepared as per the observed number of arrivals in a time interval of 20s for more than one hour of observation. These frequency tables were used to evaluate values of mean and variance of vehicle arrival rate. Then statistical analysis of data was performed. The statistical distributions are analysed to fit the observed vehicle arrival data on highway locations. Chi-square test of goodness of fit was applied for testing the hypothesis. Table 2 gives the data for fitting of Poisson distribution to vehicle arrival at Section-I. The calculated value of chi-square is obtained as 9.83, which found to be less than the tabulated value of Chi-Square as 12.59 obtained (at 6 degrees of freedom) at 5% level of significance. Hence, the null hypothesis (H_0) is accepted stating that the observed arrival pattern follows Poisson distribution on Section-I. Figure 1 shows the histogram of vehicles arrival pattern at Section-I. Similarly, Poisson distribution was also tried with the data obtained at other section. Figure 2 show the histogram of vehicle arrivals at Section-V.

Table 2. Fitting of Poisson distribution to arrival data at Section-I

Number of vehicles in 20 sec interval (x)	Observed frequency (O_f)	$(x \times O_f)$	$((x-\mu)^2 \times O_f)$	Estimated frequency by Poisson distribution (E_f)	E_f (after Pooling)	O_f (after Pooling)	$\chi^2 = ((O_f - E_f)^2 / E_f)$
0	3	0	52.78	3	--	--	--
1	14	14	142.86	11	14	17	0.64
2	24	48	115.57	24	24	24	0.00
3	39	117	55.64	33	33	39	1.09
4	23	92	0.87	35	35	23	4.11
5	33	165	21.41	30	30	33	0.30
6	16	96	52.16	21	21	16	1.19
7	13	91	102.32	13	13	13	0.00
8	8	64	115.86	6	10	15	2.50
9	3	27	69.28	3	--	--	--
10	3	30	101.11	1	--	--	--
11	1	11	46.32	0	--	--	--
	180	755	876.19	180			9.83

Null hypothesis H_0: Arrival pattern observed at Section-I follow Poisson distribution.
Alternative hypothesis H_1: Arrival pattern observed at Section-I do not follow Poisson distribution.

Mean rate of arrival (μ)= $\frac{\sum(x * o_f)}{\sum o_f}$ =4.194 sec

Variance of arrivals (σ^2) from mean= $\frac{\sum((x-\mu)^2 * o_f}{\sum o_f - 1}$ = 4.895 sec

Degree of Freedom (υ) = 8-2 = 6
At, υ = 6 and α = 5% χ^2(tabulated)= 12.59
χ^2(calculated)< χ^2(tabulated)
Hence, null hypothesis H_0 is accepted.

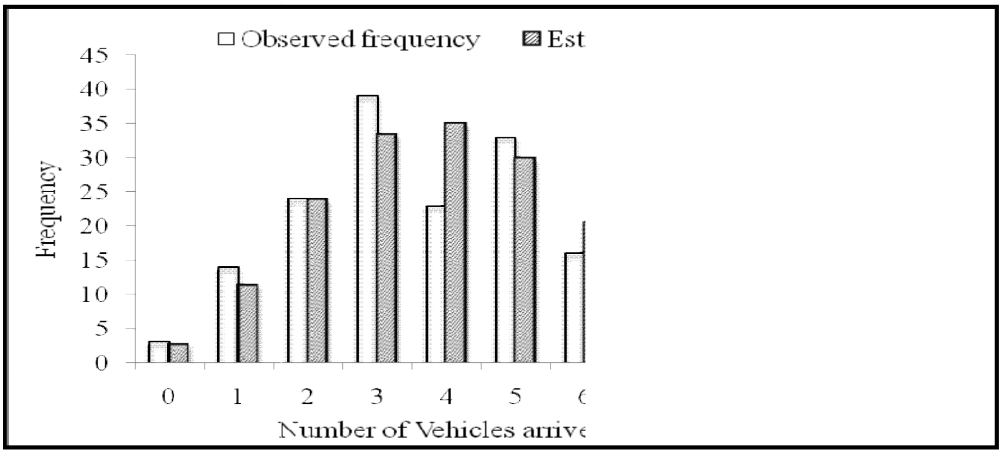

Figure 1. Comparison of histograms of vehicle arrivals at Section-I

Null hypothesis H0: The arrival pattern at Section-V follows Poisson distribution.
Alternative hypothesis H1: The arrival pattern at Section-V does not follow Poisson distribution

Mean rate of arrival (μ)= $\frac{\sum(x * o_f)}{\sum o_f}$ = 9.90 sec

Variance of arrivals (σ^2) from mean = $\frac{\sum((x-\mu)^2 * o_f}{\sum o_f - 1}$ = 13.65 sec

Degree of Freedom (υ) = 12-2 = 10
At, υ = 10 and α = 5% χ^2(tabulated) = 18.31
χ^2(calculated)< χ^2(tabulated)
Therefore, null hypothesis H0 is accepted.

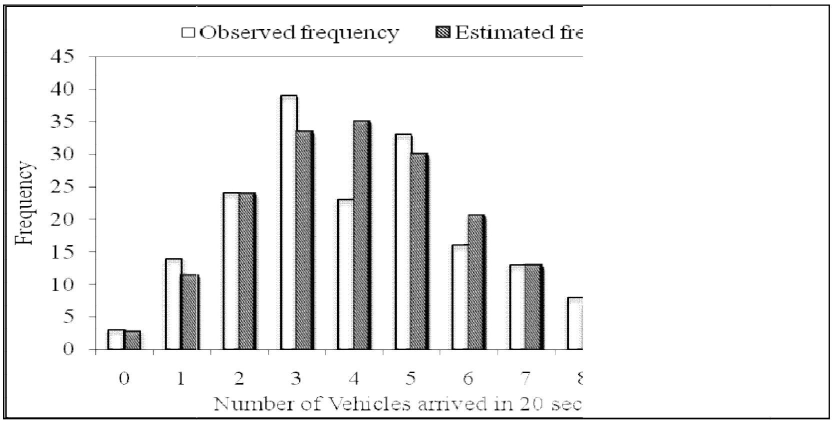

Figure 2. Comparison of histograms of vehicle arrivals at section-V

3. Time Headway Characteristics

The time headway data of each vehicle observed in recorded videos were extracted in 20 sec. interval. The descriptive analysis was performed with extracted data to understand its basic characteristics. The parameters those describe the basic characteristics such as mean and variance of data are given in the Table 3 for Section-I, Section-V and Section-VII respectively.

Table 3. Descriptive parameters of time headway data

	Section-I	Section-V	Section-VII
Mean (sec)	4.48	2.41	2.98
Median (sec)	3.71	1.71	2.21
Standard deviation (sec)	3.31	2.09	2.49
Sample size (N)	590	1400	1100

It is known that the time headway of vehicles is affected by the traffic volume observed on highway section. It has also been observed that the mean time headways, median values and standard deviation found to be decreased with increase in traffic volume ranges. The decreasing trend clearly indicates that the proportion of free-flowing vehicles is lesser in high volume a range which is resulted in smaller time headways. However, in all cases the median values of time headways are found to be smaller than the mean, infers more than 50% of drivers chose time headways lesser than their mean values

Table 4. Average time headway (sec) of vehicle types

Vehicle Type	Section-I	Section-V	Section-VII
CS	3.96	1.83	2.69
CB	4.04	1.73	2.72
LCV	4.10	1.83	2.78
HV	4.16	2.17	2.76
MAV	4.66	3.63	2.77
TW	4.48	2.07	2.68
3W	4.43	1.64	2.76
B	4.58	2.64	2.72

In order to fit different probability distribution functions to the time headway data, 5% of long time headways may be neglected and statistical results for different flow levels will be evaluated by considering 95% time headway values. In the present study, goodness of fit for each probability density function is tested by performing Kolmogorov-Smirnov (K-S) test at 5% significance level. The results of time headway distributions analysis for different study sections based on K-S test are given in Table 5.

Table 5. Estimated parameters of the best fitted distributions for Time headway data at different study sections

Sections	Best fit	Parameters	K-S Test Value	K-S Test Critical Value
I	Pearson6	α_1=1.53 α_2=89.8 β=26158.0	0.04166	0.05581
	Gamma	α=1.46 β=3.057	0.04429	
	Weibull	α=1.1238 β=5.0426	0.04470	
V	GEV	k=0.258 σ=1.096 μ=1.402	0.03587	0.03618
VII	GEV	k=0.159 σ=1.59 μ=1.76	0.03495	0.04096

From Table 5, it is observed that Pearson6 is found to be the best fit for headway data on Section-I whereas, GEV distribution is fitted best to the time headway data observed on Section-V and Section-VII. In addition, Gamma and Weibull distributions are also found suitable to fit time headway distribution at Section-I.

4. Speed Characteristics

Speed of vehicles on a traffic facility is expected to follow a normal distribution. Under the set of circumstances, where a normal distribution fails to provides a better fit to the speed data, gamma distribution or lognormal distribution are also used. Many researchers claim that the speed data on a section of highway follow the normal or gamma or log normal distribution.

For present study, the profiles of observed speed frequencies were developed and compared them with the above stated distributions for all the study sections. Chi-square test, K-S test and Anderson Darling test were applied at 5% level of significance and test of hypothesis was performed. The results from the goodness of fit tests conducted on speed data are summarized in Table 6

Table 6. Goodness of fit tests of the fitted distributions for different study sections

Distribution	Goodness of fit	Section I	Section II	Section III	Section IV	Section V	Section VI	Section VII	Section VIII
Normal	Chi-squared test	Not follow	Not follow	Not follow	Not follow	Follow	Not follow	Not follow	Not follow
	K -S test	Not follow	Not follow	Not follow	Not Follow	Follow	Follow	Not follow	Follow
	Anderson Darling test	Not follow	Not follow	Not follow	Not Follow	Follow	Follow	Not follow	Follow
Log-Normal	Chi-squared test	Not follow	Not follow	Follow	Not follow	Not follow	Follow	Not follow	Not follow
	K -S test	Follow	Not follow	Follow	Not Follow	Not Follow	Follow	Follow	Not follow
	Anderson Darling test	Follow	Not follow	Follow	Not follow	Not follow	Follow	Follow	Not follow
Gamma	Chi-squared test	Not follow	Not follow	Follow	Not follow	Follow	Follow	Not follow	Not follow
	K- S test	Not follow	Not follow	Follow	Not follow	Follow	Follow	Not follow	Not follow
	Anderson Darling test	Not follow	Not follow	Follow	Not follow	Not Follow	Follow	Not follow	Not follow

It is confirmed by the results obtained from different tests of goodness of fit that the observed speed frequencies at Section-I, Section-III, Section-VI and Section-VII follows lognormal distribution and at Section-V, Section-VI and Section-VIII it follows normal distribution. Moreover, the speed frequencies are observed to be followed gamma distribution at Section-III, Section-V and Section-VI. However, Speed data collected at Section-II and Section-VI does not follow any of these three distribution types.

Table 7 presents stated probabilistic distributions fitted to the speed data along with their estimated parameters. The results obtained from the various tests conducted to confirm the goodness of fit are also given in this table.

Table 7. Estimated parameters of the fitted distributions for speed data at different study sections

Section	Distribution	Parameters	K-S Test Value	Critical K-S Test Value
I	Log-Normal	σ=0.28418 μ=3.8661	0.02883	0.03223
III	Log-Normal	σ=0.28477 μ=3.8853	0.02512	0.04519
	Gamma	α=12.773 β=3.9654	0.0327	
V	Normal	σ=13.316 μ=63.266	0.07281	0.03123
	Gamma	α=22.572 β=2.8028	0.02633	
VI	Normal	σ=12.146 μ=50.818	0.01897	0.1182
	Log-Normal	σ=0.24165 μ=3.8995	0.08143	
	Gamma	α=17.505 β=2.903	0.07793	
VII	Log-Normal	σ=0.253 μ=4.1303	0.03101	0.03736
VIII	Normal	σ=14.616 μ=77.989	0.03441	0.03714

Conclusions

On the basis of Vehicle arrival, time headway and speed data collected from multilane highways were analyzed. Further, analysis of the collected field data was also conducted to obtain the distribution patterns for the entire traffic stream. Following conclusions are drawn from the study

1 From the Chi-square test as goodness of fit, observed arrival pattern follows Poisson distribution at Section-I and Section-V.

2 Pearson6 distribution is found to be the best fit for headway data on Section-I whereas, GEV distribution is fitted best to the time headway data observed on Section-V and Section-VII. In addition, Gamma and Weibull distributions are also found suitable to fit time headway distribution at Section-I.

3 From the K-S test as goodness of fit, the observed speed frequencies at Section-I, Section-III, Section-VI and Section-VII follows lognormal distribution and at Section-V, Section-VI and Section-VIII it follows normal distribution. Moreover, the speed frequencies are observed to be followed gamma distribution at Section-III, Section-V and Section-VI. However, Speed data collected at Section-II and Section-VI does not follow any of these three distribution types.

The results of this study can be used in various traffic applications namely geometric design, capacity estimation, safety analysis and level of service analysis. The findings of this paper can also be directly used as an input in developing micro-simulation models.

References

1 Frydenberg, E. (2008). Adolescent coping: Advances in theory, research and practice. Routledge.

2 Boora, A., Ghosh, I., Chandra, S., & Rani, K. (2018). Measurement of free-flow conditions on multilane intercity highways under heterogeneous traffic conditions. Journal of the South african institution of civil engineering, 60(1), 2-9.

3 Carnahan, J. V., Miller, K., & Segan, E. (1991). Leak location and repair cost for underground heat distribution systems. Journal of transportation engineering, 117(3), 265-280.

4 Dixon, K. K., Wu, C. H., Sarasua, W., & Daniel, J. (1999). Posted and free-flow speeds for rural multilane highways in Georgia. Journal of transportation engineering, 125(6), 487-494.

5 Zhou, Q., & Liu, C. Y. (2014). Air ticket pricing model of multi-leg airline considering No-Show. Journal of Transportation Systems Engineering and Information Technology, 14(4), 201-208.

6 Hustim, M. R., & Isran, M. (2013). The vehicle speed distribution on heterogeneous traffic: Space mean speed analysis of light vehicles and motorcycles in makassar-indonesia. In Proceedings of the Eastern Asia Society for Transportation

Studies (Vol. 9, pp. 599-610).

7 Alessandrini, A., Campagna, A., Delle Site, P., Filippi, F., & Persia, L. (2015). Automated vehicles and the rethinking of mobility and cities. Transportation Research Procedia, 5, 145-160. https://www.researchgate.net/publication/288934794

8 Panichpapiboon, S. (2015). Time-headway distributions on an expressway: case of Bangkok. Journal of Transportation Engineering, 141(1), 05014007.

9 Prahara, E., & Prasetya, R. A. (2018). Speed–volume relationship and headway distribution analysis of motorcycle (case study: Teuku Nyak Arief Road). In IOP Conference Series: Earth and Environmental Science (Vol. 106, No. 1, p. 012027). IOP Publishing.

10 Riccardo, R., & Massimiliano, G. (2012). An empirical analysis of vehicle time headways on rural two-lane two-way roads. Procedia-Social and Behavioral Sciences, 54, 865-874.

11 Ranjeeth, S., & Latchoumi, T. P. (2020). Predicting Kids Malnutrition Using Multilayer Perceptron with Stochastic Gradient Descent. Rev. d'Intelligence Artif., 34(5), 631-636.

12 Prasath, D. S., & Selvakumar, A. (2015). A Novel Iris Image Retrieval with Boundary Based Feature Using Manhattan Distance Classifier. International Journal Of Innovative Technology And Creative Engineering (Issn: 2045-8711) Vol, 5.

13 Balamurugan, K. (2021). Fracture analysis of fuselage wing joint developed by aerodynamic structural materials. Materials Today: Proceedings, 38, 2555-2562.

14 Roy, R., & Saha, P. (2018). Headway distribution models of two-lane roads under mixed traffic conditions: a case study from India. European transport research review, 10(1), 1-12.

15 Velmurugan, S., Madhu, E.,and Reddy, T. S. (2002). Changing speeds of operation on rural highways. Proceedings of National Seminar on Road Transportation in India: Emerging Trends and Techniques, September 12-13, IIT Kharagpur, Kharagpur, India, 5.29-5.40.

16 Wang, Y., Dong, W., Zhang, L., Chin, D., Papageorgiou, M., Rose, G., & Young, W. (2012). Speed modeling and travel time estimation based on truncated normal and lognormal distributions. Transportation research record, 2315(1), 66-72.

17 Xue, C., Zhao, J., & Pei, Y. (2009). Research on the characteristics of time headway distribution in expressway weaving section of type A. In ICCTP 2009: Critical Issues In Transportation Systems Planning, Development, and Management (pp. 1-7).

18 Navandar, Y. V., Dhamaniya, A., & Patel, D. A. (2020, February). Headway distribution for manually operated tollbooths in India in mixed traffic conditions. In Proceedings of the Institution of Civil Engineers-Transport (Vol. 173, No. 1, pp. 30-38).

19 Zou, Y. (2013). A Multivariate Analysis of Freeway Speed and Headway Data (Doctoral dissertation).