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A Descriptive Study of Vehicle-Type-Specific Headways under Mixed Traffic

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Abstract

This paper presents an investigation on vehicle-type-specific headways under mixed traffic. On the basis of field study conducted on a two-lane national highway in India, the paper demonstrates that both, traffic composition and lead-lag vehicle combination collectively have an effect on drivers' behavior in choosing headways. Four vehicle pairs namely, truck-truck, car-car, truck-car and car-truck were taken into consideration and three different traffic mixes were selected in a way such that they have 20 percent heavy and 15-5 percent three wheeled vehicles in composition at the time of analysis. Empirical investigation indicates that probability of shorter headways increases with the increase of three wheelers in traffic due to frequent formation of platoons. Also, the paper indicates that such probability is quite high in case of car-car combination whereas for truck-truck it was least; this is primarily caused by static and dynamic characteristics of these vehicles. However, truck drivers' keep relatively shorter headways and exhibit different driving psychology in the event of following a car. A car in general keeps adequate headway while following a truck except the case when the proportion of slower vehicles like, three wheelers and non-motorized ones in traffic is significantly less. Observation indicates that in such situation overtaking opportunities increase to a large extent and most of the cars start moving with shorter headways even if they follow a truck while taking overtaking decisions.

*Keywords:*Two-lane roads; mixed traffic; vehicle-type-specific headway; distributions; goodness-of-fit

1. Introduction

Time headway is defined as the time interval (seconds) between two successive vehicles as they cross a reference point. It is an important microscopic traffic flow parameter affecting safety, level-of-service, lane changing behavior and capacity of roads (Ye and Zhang 2009). Modeling of time headway has, therefore, been a research topic over the past few decades and traffic analysts are in search of having appropriate distribution to perform gap acceptance

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studies (Sullivan and Troutbeck 1994), car-following interaction studies (Dijker et al. 1997) and also, computer simulation to realistically generate vehicle dynamics in microscopic simulation models (Yin et al. 2009). The search is not yet over and researchers are still working on reliable description of headways by using distribution functions. Thus, it is imperative to identify the specific distribution for a given roadway and traffic condition.

Negative exponential distribution (Cowan 1975) is traditionally used; however, there have been a number of researchers who proposed a large number of models for describing headway distribution. For instance, gamma and lognormal distributions (Greenberg 1966; Mei and Bullen 1993) were found to exhibit their aptness at car-following situation. A fairly recent study reported that of these distributions are effective even if the traffic is mixed in character (Dey and Chandra 2009). Accuracy of predictive models increases further if the distributions are shifted: an experience on urban arterials reveals that lognormal model with 0.24 s shifts and gamma model with 0.69 s shifts provide a decent fit (Abtahi et al. 2011).

Arrival pattern of vehicles changes considerably with the flow resulting in a simultaneous change in headway characteristics which may consequence different distributions to work better at different flow conditions. A study investigated this fact and concluded that at low flow negative exponential distribution fits well while shifted exponential, gamma and erlang exhibit compatibility respectively at moderate and heavy flow (Al-Ghamdi 2001). Further, in case of two-lane roads where interaction between vehicles takes place in both the directions, inverse weibull distribution was found appropriate while describing headway data (Riccardo and Massimiliano 2012).

A spectrum of studies on headway distribution has been done for mixed traffic as well. In an early research on such traffic, negative exponential and shifted exponential distributions were reported to be suitable respectively at a flow level of 500 vph and higher (Katti and Pathak 1985). Almost at the same time, couple of studies conducted on urban roads also proposed shifted exponential distribution (Mukherjee et al. 1988) and three parameter exponential model (Katti et al. 1988). Another experience on urban roads with more or less similar traffic, however, suggests the use of hyperlang distribution (Chandra and Kumar 2001). A few studies, along those lines, eventually substantiate the aptness of erlang and double exponential (Isaac and Veeraragavan 1995), negative exponential (Ramanayya 1980; Kumar and Rao 1998; Arasan and Koshy 2003) and lognormal (Hossain and Iqbal 1999) distributions for the purpose of modeling headways.

Application of single distribution is, on the other hand, somewhat impractical in the event of significant proportion of shorter headways in traffic. Such traffic, in fact, calls for an approach that takes following and free vehicles into consideration separately at the time of modeling; mixed distribution model is found appropriate in such situation. Several mixed models have been developed and tested for decades; they are Cowan's M1–M4 model (Cowan 1975), double displaced negative exponential distribution model (Zhang et al. 2007) and the generalized queuing model (Branston 1976). Cowan's M3 model, however, has been extensively used for modeling headways. The advantages that it offers over other types of mixed models are it is relatively simpler and gives more realistic results especially for longer headways (Tanyel and Yayla 2003; Zhang and Wang 2013).

In majority of the studies cited above, the traffic stream is represented in an aggregate manner and a handful of studies that have made analysis at disaggregate level indicate significant difference between vehicle-type-specific and mixed vehicle-type headways. Moreover, different combinations of leading-following vehicle pairs result in different headway scenarios: for instance, erlang (Ye and Zhang 2009) and lognormal (Weng et al. 2014) distributions in the event of car-truck headway; shifted negative exponential (Ye and Zhang 2009) and inverse gaussian (Weng et al. 2014) distributions in the event of truck-car and truck-truck headways; composite model, i.e. a combination of negative exponential and shifted negative exponential distributions (Ye and Zhang 2009) and lognormal distribution (Weng et al. 2014) in the event of car-car headway. Further, a few studies used generalized queueing model (Hoogendoorn and Bovy 1998), nonparametric model with gaussian kernel (Dong et al. 2015) and lognormal (Kanagaraj et al. 2010) distributions to model vehicle-type-specific headways.

Most of the existing research on headway focuses on homogeneous traffic and only a few studies that have so far addressed mixed traffic do not, however, adequately describe the characteristics of headways if the prevailing traffic is composed of a wide range of vehicle types including non-motorized ones. Impact of such traffic aggravates further especially on two-lane roads where a single carriageway is used by both direction traffic. It is, therefore, worthwhile to do more research on vehicle time headways based on two-lane highway data. This fact along with the pressing need of developing capacity standards under mixed traffic have been the motives for conducting the current research.

Nomenclature

SD	standard deviation
CV	coefficient of variation
K-S	Kolmogorov Smironov
GQM	generalized queueing model
MLE	maximum likelihood estimation
h	time headway of vehicles
f (h), $f(h_i \vert \hat{\theta})$	probability density function
λ	continuous inverse scale parameter
m	shape parameter (positive integer)
β	continuous scale parameter (Erlang distribution)
α	continuous shape parameter
σ	continuous scale parameter (Lognormal distribution)
μ	continuous location parameter
$\hat{\theta}$	parameter vector

2. Objective of the paper

The premise on which the current study is based considers two-lane roads where the prevailing traffic is mixed in character and composed of a wide variety of vehicle types in terms of their static and dynamic characteristics. Since drivers' behavior in choosing headways largely depends on lead-lag vehicle types and also, the interference caused by slower vehicles, the study made an attempt to investigate the impact of vehicle pair combination and slower vehicles on characteristics of headways. In most of the Indian highways, it is observed that usually car, truck and two-wheeler have the highest share in the overall traffic. Physical (larger length) and operational (low acceleration-deceleration and braking capabilities) characteristics of truck traffic have an impact on vehicle following interaction. For an instance, car-truck interaction is often observed to be quite different than that of truck-car interaction. Interestingly, on highways the majority of the two-wheelers are observed to be reluctant to move in following and they frequently attempt to overtake disobeying lane discipline; their physical characteristic permits them to complete such overtaking even on the same lane (they do not shift to the adjacent lane if the gap is not acceptable) and consequently move with widely spaced headways. Interaction of car and truck in the traffic stream is, therefore, considered critical from the perspective of safe and efficient operations of traffic. Accordingly, the paper aimed at meeting the following objectives:

- Developing best fitted distribution model for headways considering different leader-follower combinations under diverse traffic condition in terms of composition
- Investigating the characteristics of headways at different vehicle pair interactions: for instance, truck-truck, truck-car, car-truck and car-car

3. Methodology

3.1. Headway distribution modeling

Typically, negative exponential distribution is used to describe the distribution of headways. However, over the past few decades, compatibility of several alternative statistical models have been tested and proposed for the purpose of modeling headway data. Several studies indicate that under car-following situations headways are lognormally distributed (Greenberg 1966; Mei and Bullen 1993; Jang 2012) while gamma (Zhang et al. 2007; Abtahi et al. 2011),erlang (Al-Ghamdi 2001) and weibull (Weng 2014;Yin et al. 2009) distributions are preferred to fit data because of their flexibility and compatibility in approximating headways. Further, at congested flow of traffic, mixed headway distribution models have been found to better capture headway dynamics. Parameter estimation of most of such mixed models is, however, somewhat difficult (Zhang et al. 2007). Although, Cowan M3

(Cowan 1975), one of such mixed models, is considered better in terms of its simplicity and ease in modeling headway data, it did not give satisfactory result under mixed traffic where proportion of shorter headways is significant (Roy and Saha 2018).

The lookout of the current study was, therefore, to identify appropriate headway distribution functions for mixed traffic. Over the past few decades, a number of studies have tested compatibility of different distributions under such traffic and Erlang (Isaac and Veeraragavan 1995; Saha et al. 2017), lognormal (Katti and Pathak 1985; Hossain and Iqbal 1999; Kumar and Chandra 2001; Kanagaraj et al. 2011; Suresh et al. 2014; Mourya et al. 2015; Sohrabi et al. 2016; Saha et al. 2017), gamma (Kanagaraj et al. 2011;Mourya et al. 2015; Sohrabi et al. 2016; Saha et al 2017) and Weibull (Kanagaraj et al. 2011; Mourya et al. 2015; Sohrabi et al. 2016) were found to exhibit aptness in modeling headways in most of those studies. The paper, therefore, considered these models as candidate distributions (see Eq. 1-5) to study vehicle-type-specific headways.

Negative exponential distribution:

$$f(h) = \lambda\, exp(-\lambda h) \tag{1}$$

Erlang distribution:

$$f(h) = \frac{h^{m-1}}{\beta^m \Gamma(m) \times exp\left(-\frac{h}{\beta}\right)} \tag{2}$$

Lognormal distribution:

$$f(h) = \frac{1}{h\sigma\sqrt{2\pi}} \times exp\left(-\frac{(ln\, h-\mu)^2}{2\sigma^2}\right) \tag{3}$$

Gamma distribution:

$$f(h) = \frac{h^{\alpha-1}}{\beta^\alpha \Gamma(\alpha)} \times exp(-h/\beta) \tag{4}$$

Weibull distribution:

$$f(h) = \frac{\alpha}{\beta}\left(\frac{h}{\beta}\right)^{(\alpha-1)} exp\left(-\left(\frac{h}{\beta}\right)^{\alpha}\right) \tag{5}$$

Where, f (h) = Probability density function; λ= continuous scale parameter (λ>0); m= shape parameter (positive integer); β= continuous scale parameter(Erlang distribution) (β>0); Γ= Gamma function; σ = continuous scale parameter (Lognormal distribution) (σ>0); μ= continuous location parameter; α = continuous shape parameter (α> 0).

3.2. Data collection

Field study was conducted on a two-lane highway (NH-8) that passes through Tripura, a state in north east India: 7 m wide carriageway and 1.5 m earthen shoulder on either side of the road. The highway connects Agartala city, the capital of the state of Tripura, at its western end and serves as a major arterial to the residents of the city outskirts. However, lack of adequate public transport facility has resulted in simultaneous growth of para transit modes of transportation like, three wheeler and non-motorized modes. Evidently, the traffic composition at the highway section passing through such moderately developed areas is quite different than that of rural highway section. In order to capture the impact of compositions on traffic operations, three study sites were selected on the highway in a way that they have different proportion of paratransit in traffic mix. Further, study sites were selected at tangent section without vertical and horizontal curvature such that visibility problem does not arise and they were

Fig. 1.Camera view at study sites (photo by authors)

devoid of any influence of intersections, fuel stations and any road side activities that might interfere with traffic. Pavement condition was good and uniform at all the study sites (see Figure 1).

Following the experience that has gathered from past research, it was decided to adopt video photographic survey technique for the purpose of collecting time headway data. To collect the data, a reference line was marked on the pavement surface and two video cameras were installed: one in each direction to record the time when the front and rear ends of any vehicle cross the reference line. Each selected road segments were videotaped continuously for a period of two hours in the daylight hours at moderate flow level of traffic that corresponds to a volume to capacity ratio of 0.5 to 0.6: derived from a capacity value of 2300 pc/h (Saha et al. 2017). All measurements were made in good weather condition; pavement surface was dry and visibility was good. The necessary readings i.e. vehicle type, entry and exit time of front and rear ends of the vehicles were extracted from the recorded video files. Time headways between successive vehicles were determined using entry or exit time of vehicles. The observed vehicles in the traffic mix were then classified into six categories: car, two-wheeler, bus, truck, three wheeler and non-motorized vehicles (NMV).

4. Analysis and results

4.1. Characteristics of field data

Characteristics of headway data largely depend on composition and flow rate of traffic. Experiences with mixed traffic reveal the fact that in addition to truck, three wheeled and non-motorized vehicles also have significant impact on headway distribution. However, a handful studies have so far investigated such impact and thus, the primary motives of the paper was to perform headway analysis under different proportion of those vehicle types.

Analysis of field data collected at three road segment explicates that share of three wheeler and non-motorized modes are reasonably high at the road segment closer to the city which however starts diminishing as the study segments move on to the rural section of the highway. Figure 2 displays the composition of traffic observed at the road segments. Road segments catering the needs of residents living at city outskirts have 10-15 percent three wheeler and 5-10 percent NMV in traffic mix (see Figure 2.a-b). While, at rural section it was observed to reduce to a large extent; in a way that in the composition NMV disappears and three-wheeler reduces to about 5 percent (see Figure 2.c). Since, all the study segments were selected on the same highway section, variation in the proportion of truck, car and two-wheeler was found to be insignificant. The paper accordingly considered three different compositions (composition 1, 2 & 3) considering three wheeler (15, 10 & 5 percent) and truck (20 percent) as heavy vehicle. Four vehicle pairs were considered critical for the purpose of analysis; they are: truck-truck, car-car, truck-car and car-truck. Two-wheeler and NMV were not considered as they were not observed to move in following particularly at moderate flow of traffic; NMV shifts to the adjacent shoulder when they are entrapped inside platoons and two-wheeler performs risky overtaking operations in most of the instances.

Figure 3 shows the histograms of headway data obtained for the four leader-follower vehicle pairs considered in the study. Regardless of traffic compositions, the histograms were observed to be highly right skewed especially for car-car and car-truck combinations indicating higher proportion of shorter headways. Examination of field data shows that at moderate flow, formation of platoons are frequent and a car, which is entrapped inside a platoon, moves with shorter headways while taking overtaking decisions. Interestingly, they were observed to keep reasonably safe distance in the event of following a truck. Truck drivers, on the other hand, follow a car with shorter headways; this is possibly due to drivers' psychology which compels them to take such decisions. A look into Table 1 reveals that mean headway of truck-truck combination is higher compared to the rest and the value increases when proportion of three wheeled vehicles in the traffic stream starts reducing; this attributes to lower frequency of platooning in traffic.

(a) (b) (c)

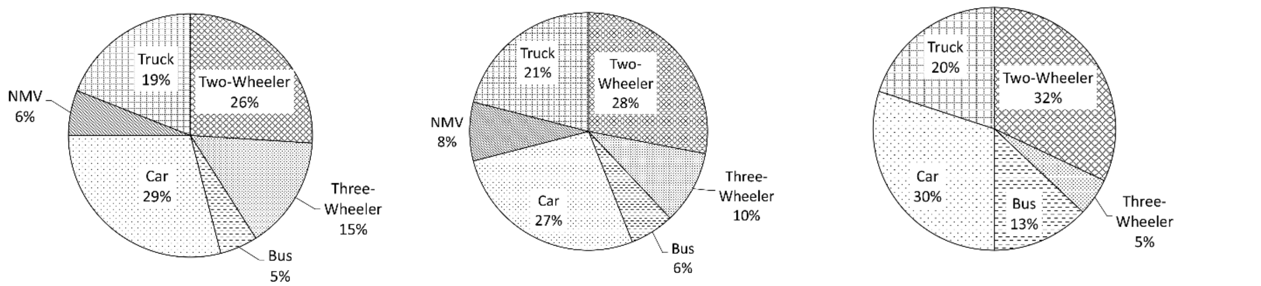


Fig.2. Traffic composition observed at the study sites: (a) composition 1 (20 percent heavy vehicle and 15 percent three wheeler); (b) composition 2 (20 percent heavy vehicle and 10 percent three wheeler); (c) composition 3 (20 percent heavy vehicle and 5 percent three wheeler)

(a) (b) (c)

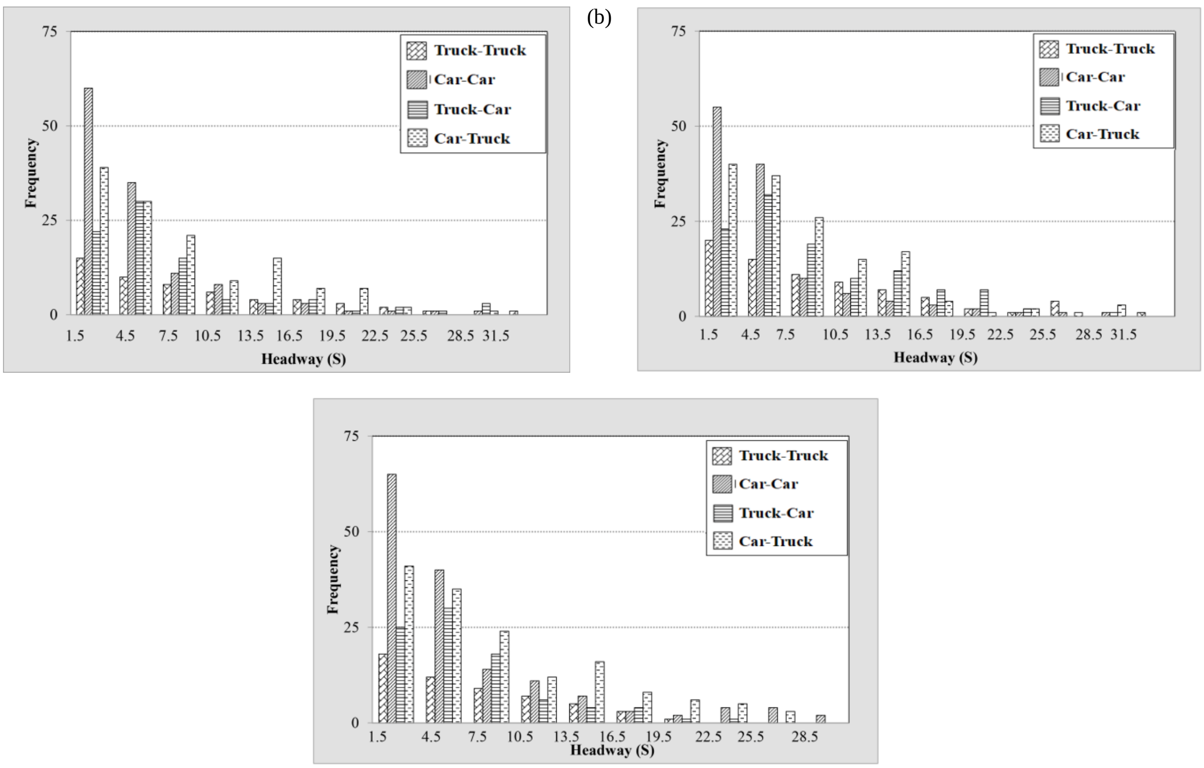


Fig.3. Histograms of critical vehicle-type-specific headways observed under: (a) composition 1; (b) composition 2; (c) Composition 3

Table 1.Descriptive statistics of vehicle-type-specific headways

Headway Type	Composition 1				Composition 2				Composition 3			
	Mean	SD	CV	Skewness	Mean	SD	CV	Skewness	Mean	SD	CV	Skewness
Truck-Truck	8.5	12.87	1.51	2.41	15.66	14.89	0.95	1.29	13.13	14.5	1.1	2.68
Car-Car	3.71	2.43	0.65	2.31	4.53	3.02	0.67	0.36	4.67	3.32	0.71	2.49
Truck-Car	6.43	9.4	1.46	2.23	6.54	5.39	0.82	1.23	8.05	10.22	1.27	1.94
Car-Truck	5.43	9.25	1.7	0.07	5.45	4.86	0.89	0.61	5.25	6.9	1.31	1.67

Note: SD: Standard deviation; CV: Coefficient of variation

4.2. Distribution of vehicle-type-specific headways

The histograms shown in Figure 3.a-c indicate that at moderate traffic flow (v/c ratio ranging from 0.5 to 0.6) distributions of the four vehicle-type-specific headways are fairly different: proportion of shorter headways (less than 2 s) is high in case of car-car combination whereas it is considerably less for truck-truck combination. The distribution pattern was also observed to change with traffic compositions. Inspection of three composition (see Figure 2.a-c) shows that truck is comparatively in equal proportion (about 20 percent) and three-wheeler has a consistent drop in its share. Further investigation was, therefore, carried out to understand the impact of heavy (truck) and three wheeled vehicles on headway distributions; since they have major interference in traffic operations.

The study made an attempt to fit the candidate distributions (see Eq. 1-5) to field data and thereby, explicitly explain distribution patterns of such headways. There are several methods of distribution fitting like, Maximum likelihood estimation (MLE) (Myung 2003), method of moments (Wang and Peng 2014), minimum chi-square method (Kominek 2002) and simultaneous numerical estimation (Vasconcelos 2012). The maximum likelihood method is, however, reported to be effective particularly when the sample size is not large (Luttinen 1999). Since the current investigation was conducted using field data, maximum likelihood method was applied as an effective heuristic method. Accordingly, the parameters of the distribution models were estimated (see Table 2) for the field data collected at study sites by maximizing the log-likelihood function (see Eq. 6 & 7).

Table 2. Goodness-of-fit test results and estimated parameters for the selected distribution models

Headway Type	K-S Statistic Value					P-Value	Null Hypothesis *	Parameter
	Exponential	Erlang	Lognormal	Gamma	Weibull			
Composition 1								
Truck-Truck	**0.1027(1)**	0.1583(2)	0.2109(5)	0.1901(4)	0.1826(3)	0.9988	Accepted	λ= 0.2037
Car-Car	**0.2897**(1)	No fit	0.3369(2)	0.3763(4)	0.3493(3)	0.5086	Accepted	λ= 0.18421
Truck-Car	0.3041(3)	No fit	0.2361(2)	0.3237(4)	**0.2344**(1)	0.7599	Accepted	α= 1.0224, β = 1.8055
Car-Truck	0.2452(2)	0.2606(4)	0.2861(5)	0.2485(3)	**0.2325**(1)	0.6325	Accepted	α =1.1056, β = 1.3191
Composition 2								
Truck-Truck	**0.1363**(1)	0.1408(2)	0.2431(5)	0.1593(3)	0.1942(4)	0.9698	Accepted	λ= 0.14667
Car-Car	0.1384(2)	0.1732(4)	0.1664(3)	**0.1298**(1)	0.2256(5)	0.9992	Accepted	α =1.0019, β = 1.1021
Truck-Car	0.2031(3)	0.3216(5)	**0.1401**(1)	0.1822(2)	0.2355(4)	0.9984	Accepted	σ= 1.2018, μ= 0.5111
Car-Truck	0.2555(3)	0.2984(5)	0.2507(2)	0.2733(4)	**0.2443**(1)	0.7923	Accepted	α =0.8577, β =4.7572
Composition 3								
Truck-Truck	**0.1417(1)**	0.2319(5)	0.2247(4)	0.1612(2)	0.2071(3)	0.6016	Accepted	λ= 0.1231
Car-Car	0.3065(2)	No fit	0.3099(3)	0.3343(4)	**0.2526**(1)	0.4707	Accepted	α =1.1019, β = 1.5963
Truck-Car	0.3418(4)	No fit	**0.2809**(1)	0.3099(2)	0.3177(3)	0.4706	Accepted	σ= 1.5981, μ= 1.0112
Car-Truck	0.3485(4)	0.5719(5)	0.2319(3)	0.2137(2)	**0.2014**(1)	0.7941	Accepted	α =0.7138, β = 1.9611

*Note: *At 5% level of significance on distributions having lowest K-S test statistic*

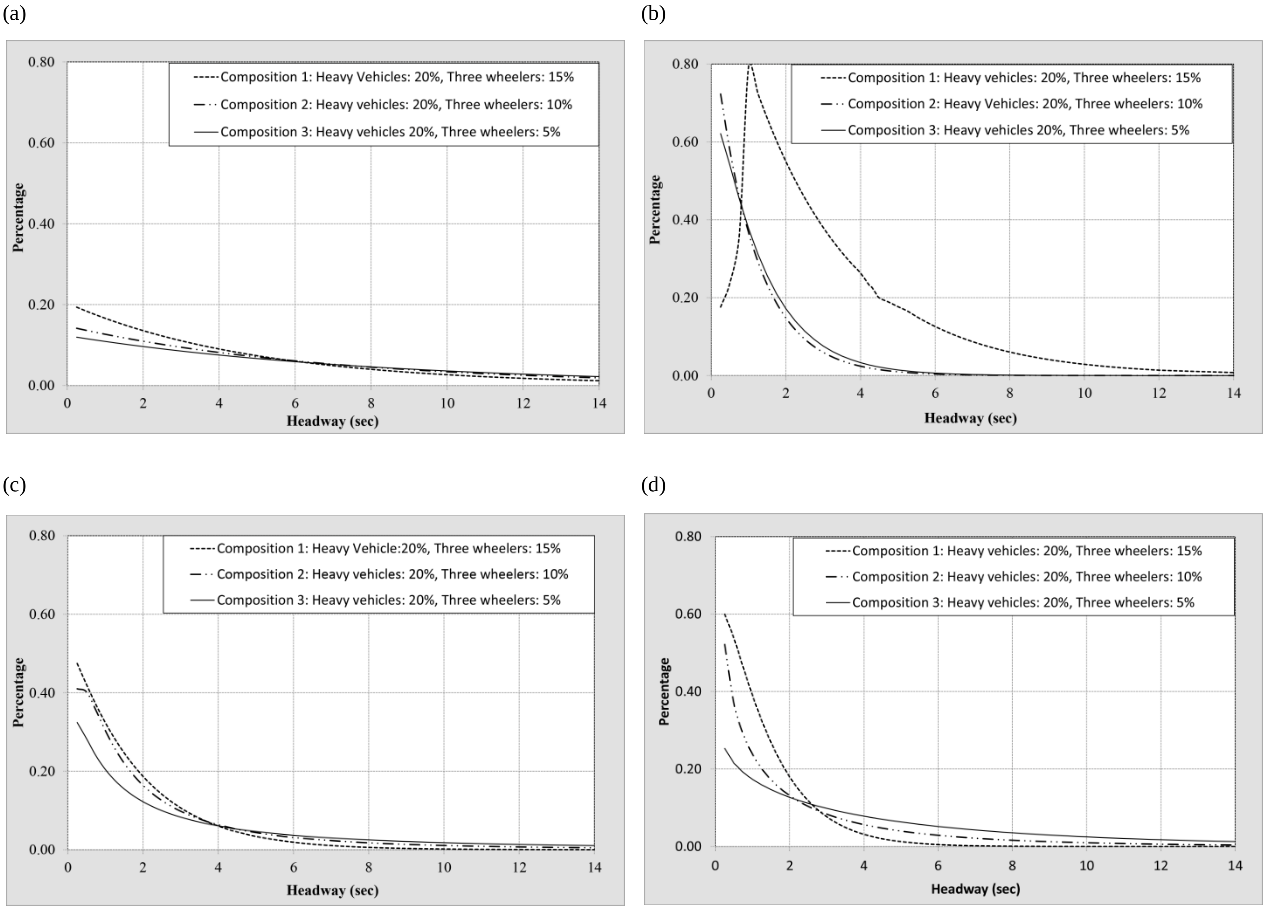


Fig.4. Probability density functions of vehicle type specific headways at three different compositions of traffic: combination (a) Truck-Truck; (b) Car-Car; (c) Truck-Car; (d) Car-Truck

$$L(\hat{\theta}) = \prod_{i=1}^{n} f(h_i|\hat{\theta}) \tag{6}$$

$$ln\, L(\hat{\theta}) = \sum_{i=1}^{n} ln\, f(h_i|\hat{\theta}) \tag{7}$$

Where, $\hat{\theta}$ = parameter vector and $f(h_i|\hat{\theta})$ = probability density function

Goodness-of-fit tests were subsequently conducted to know how well the distribution fits to the headway data. In traffic analysis, chi-square and K-S tests are extensively used; however, K-S test was found to be suitable for data with a continuous distribution and also, from the ground that there is no restriction of minimum frequency per test interval (Ye and Zhang 2009). Accordingly, the current study applied K-S test to measure the goodness-of-fit of the selected headway models (see Eq. 1-5) at the desired significance level (α);the distributions which have smallest statistic values were considered as the best fitted model (see Table 2). The null hypotheses for each test were as follows: ‘the compatibility hypothesis of headway distribution with fitted model was rejected (P-value< α) or not rejected (P-value> α)’.

Exponential distribution was found compatible for truck-truck combination and the variation in distributions was observed to be insignificant even if three wheelers in traffic mix are in different proportion (see Figure 4.a). Observations indicate that on highway it is quite common that a truck keeps wide spacing while following another truck. This is primarily due to large size and low braking capabilities of such vehicles.

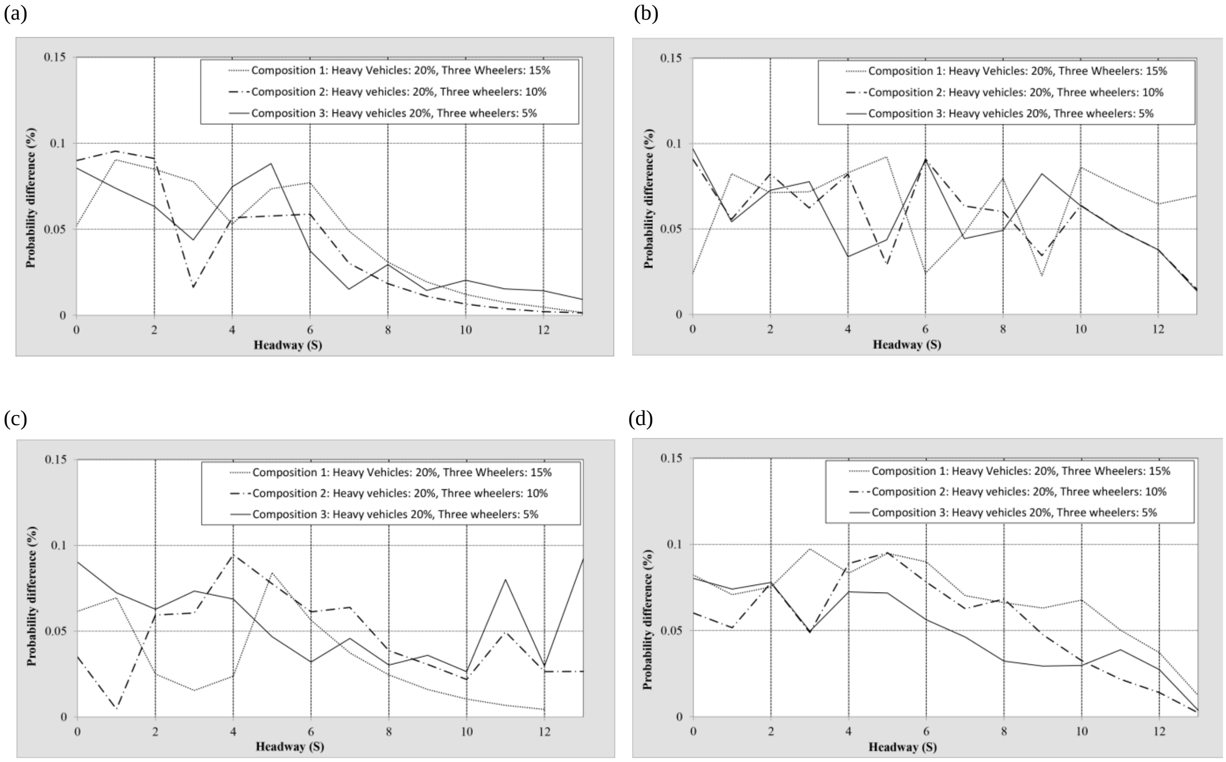


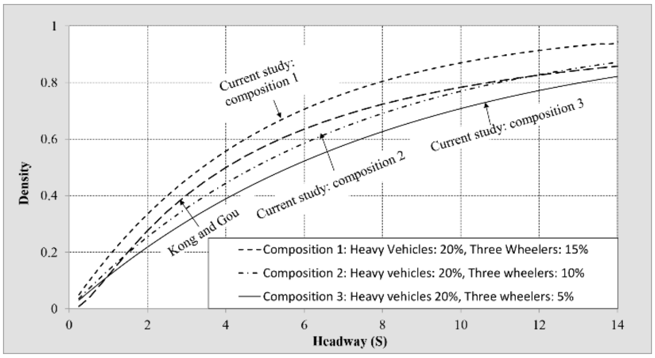
Fig.5.Differencein probability of headways between model outcomes and that obtained from a study section with more or less comparable traffic composition: combination (a) Truck-Truck; (b) Car-Car; (c) Truck-Car; (d) Car-Truck

In case of car-truck combination, weibull distribution was found to be statistically valid in terms of K-S test statistic. Notably, a truck was observed to follow a car with comparatively shorter headways; probability of which increases with the increase of three wheelers in traffic (see Figure 4.d). This attributes to drivers' psychology which encourages them to keep shorter spacing while following smaller vehicles like car. This was, however, somewhat different in the event of a car following a truck except the case when proportion of three wheeler in traffic is less (see Figure 4.c); this could be due to the fact that car drivers' habitually exhibit conservative attitude especially when they follow truck. Car drivers' were, on the other hand, observed to keep shorter headways while taking overtaking decisions if the lead vehicle is also a car; proportion of which increases significantly with three wheelers in traffic mix (see Figure 4.b). Statistical investigations indicate that lognormal distribution provides a good fit for truck-car combination when three wheelers are in the range of 5-10 percent and it is weibull like car-truck combination when percentage share of three-wheeler is about 15. In case of car-car; exponential, gamma and weibull were found compatible respectively at 15, 10 and 5 percent three wheeled vehicles in traffic (see Table 2).

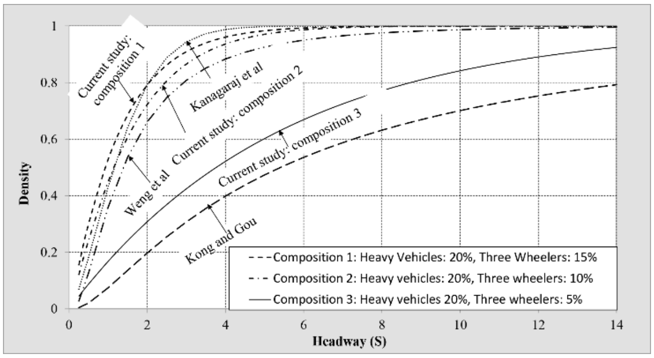
Further, a pilot study was conducted on a two-lane highway (SH-13) that exhibit similar traffic characteristics in the state of West Bengal, India in order to validate the model outcomes. Study site was selected adopting the same approach and traffic data was videotaped continuously for a period of one hour in the daylight hours at moderate traffic flow level. Subsequent analysis of data indicates that the traffic mix has more or less comparable composition and distribution of headway data is highly right skewed.

Probability differences were estimated to compare how rational the outcomes are with respect to field observations and expressed in terms of percentage. Figure 5 contemplates the probability differences and shows that such values are in conjugation with the assumed working hypothesis, i.e. less than 10 percent for all the vehicle pairs. This indicates that, there is a relatively good agreement between the model and field data. A further examination of Figure 5 reveals that except the case of car-car combination, the probability difference is invariably high at shorter headways. This could be attributed to drivers' behavior that might change with the road environment.

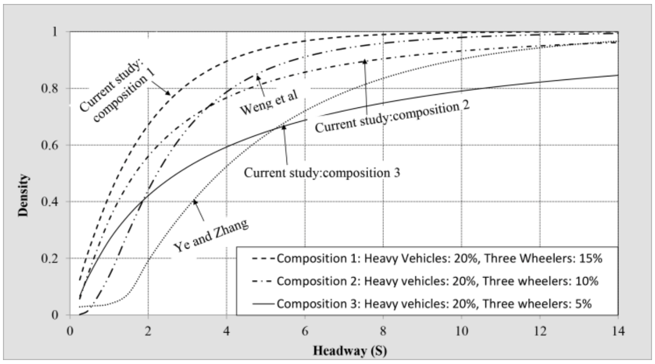
(a)



(b)



(c)



(d)

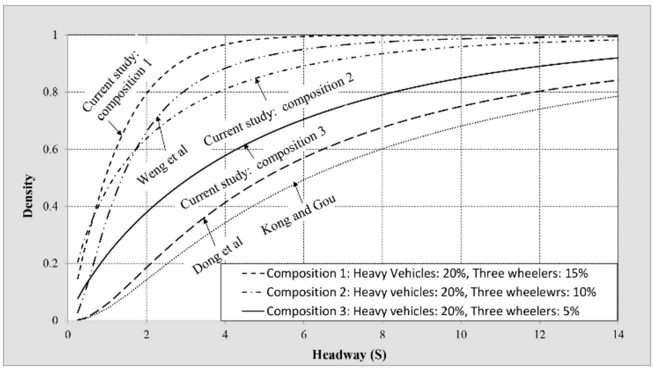


Fig.6. Comparison of vehicle-type-specific headway distributions observed in current study and case studies with relatively homogeneous traffic: combination (a) Truck-Truck; (b) Car-Car; (c) Truck-Car; (d) Car-Truck

5. Model interpretation and discussions

Apposite modeling and simulation under mixed traffic largely depends on inputs and thus, selection of distribution function for the parameters is considered as a key issue in an attempt to approximate traffic with reasonable amount of accuracy. On the basis of extensive review of literature, the paper identified a number of distribution functions and used them to statistically characterize headway data. Further, an attempt was made to examine the performance of distribution models by comparing model outputs with those obtained in studies conducted under varied roadway and traffic conditions and comparable with the current study to some extent.

Figure 6.a depicts a consistent decrease in truck-truck headway probabilities with a simultaneous reduction in slower vehicles like, three wheelers and non-motorized ones as well. Higher proportion of three wheelers (15 percent in current study) combined with heavy vehicle and NMVs increase traffic interference and thereby, resulting in substantial drop in traffic speed. Eventually, the traffic starts getting compressed and almost all the vehicles move with relatively shorter headways. However, lessening of such interaction leads to decompression and subsequent reduction in probability of shorter headways. A model developed on the basis of a study performed with freeway data wherein heavy vehicles have around 20 percent share in composition (Kong and Guo 2016) indicates that probability of shorter headways is lower than that obtained in current study with 15 percent three wheelers and also about 5 percent NMV. Differences in probability diminish substantially when three wheeled vehicles were reduced by 5 percent. A further reduction, however, consequences lower probabilities at the study site considered in the paper. This could be possibly due to the fact that drivers' behave differently in choosing headways while overtaking on one-way and two-way road segment.

Similar study was conducted for car-car combination (see Figure 6.b). Initially two case studies were considered: a four lane one way segment of an expressway, two-lanes of which are closed for the purpose of construction activity, having about 20 percent heavy vehicles in traffic mix (Weng et al. 2014) and a four lane divided urban arterial having more or less similar traffic as observed in the current study (Kanagaraj et al. 2011). Distributions of car-car headways observed at those segments were found to have similar probabilities as observed in current study when three wheeled and heavy vehicles are respectively 10-15 and 20 percent. Such agreement signifies reasonable amount of accuracy of the car-car model which substantiate the fact that majority of the car drivers' move with shorter headways while following another car. Since traffic speed increases with the declining proportion of three wheelers in traffic stream, probability of shorter headways reduces to a considerable extent and bears a resemblance to that observed on a freeway segment with comparable traffic composition (Kong and Guo 2016).

A look into the distributions of truck-car and car-truck combinations reveals that characteristics of headways observed in the current study do not vary considerably from two-lane one-way segment of an expressway (Weng et al. 2014) except the case when proportion three wheelers is 5 percent (see Figure 6.c-d).Mixed traffic results in speed reduction and frequent platooning due to impedance caused by slower vehicles like, truck, three wheelers and NMVs. As a result, vehicles entrapped inside platoons start moving in following while searching an acceptable gap to perform overtaking operations; this consequences an increase in probability of shorter headways. Further, such probability is higher in the event of car-truck combination; this could be possibly due to different driving psychology that truck driver' shows while following a car. Such compression in traffic also occurred on the expressway segment since two lanes of it was closed and the entire traffic was channelized through the remaining two lanes. Eventually, existence of relatively slower vehicles (around 20 percent heavy vehicles) and also high volume of traffic result in formation of platoons, thereby, generating large number of shorter headways. On the other hand, difference in probability of headways was not observed to be very high between current study with 5 percent three wheelers and case studies (Dong et al. 2015; Kong and Guo 2016; Ye and Zhang 2009)conducted with more or less homogeneous traffic (see Figure 6.c-d). The trends of distribution pattern were also found to be almost parallel indicating an acceptable accuracy level of the model outcomes.

6. Conclusions and further research

Over the past few years, it has been felt essential to augment capacity of highways in many places across the globe to meet the growing demands of road traffic. This warrants an accurate evaluation of capacity and level-of-service; however, it was found to be difficult in several instances especially when the traffic is mixed in character and composed of a wide range of vehicle types. To address this issue, it is imperative to develop simulation models performance of which depends on inputs into the simulation process. Since, time headway is an important microscopic traffic flow parameter; traffic analysts are in search of having reliable and practical descriptions of it to improve model performance. Experiences with mixed traffic, on the other hand, shows that modeling of headway dynamics under such traffic is somewhat complex because of the fact that lead-lag vehicle combinations have considerable impact on it. Although, a handful of studies have investigated such impacts, most of those studies were conducted with homogeneous traffic and no significant efforts have been made so far under mixed traffic. This was the motives for taking up a systematic investigation of vehicle-time-specific headways under such traffic particularly at moderate flow.

Based on field studies conducted on a two-lane national highway, the paper elucidates the fact that both, composition and leader follower combination have impacts on drivers' behavior in choosing headways. Four vehicle pairs viz. truck-truck, car-car, truck-car and car-truck were considered critical for the purpose of analysis. Further, three different traffic mix were selected in a way such that they have 20 percent heavy and 15-5 percent three wheeled vehicles in composition. Empirical investigation indicates that probability of shorter headways (less than 2 s) increases with the increase of three wheelers in traffic due to frequent formation of platoons. Further, such probability was observed to be quite high in case of car-car combination whereas for truck-truck it was least. Such paradox is due to static and dynamic characteristics of these vehicles: a car was observed to follow another car with shorter headways while taking overtaking decisions, however, truck drivers' usually do not take any attempt to overtake another truck and move with widely spaced headways. Interestingly, their driving psychology appears to be quite the opposite if the lead vehicle is a car. A car in general keeps adequate headway while following a truck except the case when NMV disappears and proportion of three wheelers in traffic composition is very small. In such context, they get ample overtaking opportunities and start following even a truck with relatively shorter headways to perform overtaking operation.

While, an appropriate modeling of time headways is the pre-requisite for capacity, level-of-service, safety and simulation studies; modeling schemes are still unclear even after decades particularly in case of mixed traffic. This is due to inherent complexities of analyzing such traffic caused by a wide range of vehicle types in terms of their static and dynamic characteristics and also, drivers' psychology and behavior. This, accordingly, entails a comprehensive understanding of vehicular interaction based on field data collected covering a range of flow scopes and traffic compositions. Further, the analytical framework of the present research can be expanded or supplemented. The paper, thus, suggests a starting point of future initiatives aimed at developing a unified approach of modeling of headways.

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