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Headway Distributions in Urban Highways under Heavy Traffic Conditions

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Abstract

Headway is an important microscopic traffic flow parameter that influences the capacity and safety of highways and freeways. Headways are extensively used in different areas of traffic and transport engineering such as capacity analysis, car following and lane changing modelling, safety studies, and level of service evaluation. In this paper, the time headway distribution is investigated for an urban highway, at different flow rates during heavy traffic conditions. To better evaluate the headway characteristics, the time headways are separately evaluated for different car following combinations including passenger car following a passenger car, passenger car following a heavy vehicle, heavy vehicle following a passenger car and heavy vehicle following a heavy vehicle. Appropriate models of headway distribution are selected using Chi-Square test. Using the selected models, headway distributions are predicted for each vehicle combination at different traffic flow rates. The trajectory data used in this study was provided for a highway section in California: Berkeley Highway, I-80. For the time intervals presented in the data, the traffic flow condition for each site reflects Level Of Service (LOS) E which is considered as heavy traffic conditions. The results confirm existence of different time headway distributions for heavy vehicles and passenger cars. This is due to the existence of limitations in performance (e.g. acceleration/deceleration) of heavy vehicles as well as the difference in the behaviour of drivers in vicinity of heavy vehicles and passenger cars under heavy traffic conditions.

Keywords: Headway, Distribution, Highways, Heavy vehicles, Passenger cars

1. Introduction

Time headway or headway is defined as the time between two consecutive vehicles (in seconds) when they pass a single point on a roadway [1]. Headway is defined as the time between the same common features of two consecutive vehicles (e.g. front bumper). Time headway is one of the important microscopic traffic flow parameters that is extensively applied in roadway design, traffic studies and analysis of transport systems [2, 3, 4, 5, 6, 7, 8, 9, 10]. Therefore, it is essential to accurately evaluate this parameter based on real behaviour of drivers at different traffic environments [11, 12, 13, 14, 15, 16, 17, 18, 19]. Understanding drivers' behaviour in selecting their desired headway is important in order to have better traffic planning and policy making at different traffic conditions. This is due to the fact that time headways and their distributions would influence different traffic flow parameters such as capacity, level of service and safety [8, 20, 21, 22]. Precise modelling and analysis of vehicle headway distributions assists in more accurately modelling the drivers' behaviour and consequently maximising roadway capacity and minimising the delays that vehicles experience [8, 19, 22, 23]. Furthermore, headway analysis is used in understanding the reasons of traffic accidents as well as evaluating policies to enhance road safety [19, 21].

In general, existing studies mainly ignore the safe headway requirements in capacity analysis and safety studies. In addition, the influence of vehicle type (heavy vehicles or passenger cars) on the minimum headway requirements is mainly ignored in previous studies. This may cause inaccurate estimation of traffic flow characteristics specifically on roadways with traffic flows less than the perceived capacity [8, 19, 24].

According to the literature, many factors influence the headway distribution of vehicles. Those factors include traffic volume, proportion of heavy vehicles, road structure, time of the day and weather condition. Accurate estimates of the headway distribution for different vehicle types and different times of the day have many applications in traffic engineering. The headway distribution estimates can be used in multi-class multi-lane vehicle generation in microscopic traffic simulation tools, lane specific capacity estimation and analysis and passenger car equivalent estimation, and the consequent application is in infrastructural design and planning, safety studies, and gap acceptance behaviour analysis [25]. In 1993, Mei and Bullen analysed different statistical distributions for time headways on a four-lane freeway during the morning peak [26]. They used a freeway data set with lane flow rates of 2,500 to 2,900 vehicles per day. According to their results, shifted lognormal distribution with a shift of 0.3 or 0.4 seconds was the most appropriate fit for the time headways in high traffic volumes. Sadeghhosseini [27] analysed and evaluated time headways at different flow rates varying from 140 to 1704 vehicles/hour/lane on interstate highways of Illinois, U.S. He also examined different distribution models that provide a good fit to time headways. According to the results of his study, using lognormal distributions with a shift of 0.36 seconds was recommended to generate the time headways of interstate highways of Illinois. In 2006, Bham and Ancha analysed the time headway behaviour of drivers in a basic freeway section as well as a ramp merge, a lane drop and a ramp weaving section in U.S. [28]. According to their study, lognormal distribution with shift of 0.21 seconds provided a good fit to time headways. Meanwhile, shifted Gamma distribution with shift of 0.21 seconds was proposed for time headways. Zhang et al. [23] comprehensively evaluated the performance of typical headway distribution models on urban freeways. They used the Advanced Loop Event Data Analyzer (ALEDA) system to provide headway observations for Interstate Highway 5 in Seattle, U.S. Using the headway data, they calibrated and examined the performance of various headway models on regular lanes as well as High Occupancy Vehicle (HOV) lanes for different time periods of day. According to their results, the shifted lognormal distribution well fitted the headways at regular lanes. Meanwhile, Double Displaced Negative Exponential distribution model provided the best fit to their urban freeway headway data, especially, for HOV lanes [23]. In 2009, Yin et al. identified appropriate models for headway distributions in Beijing, China [29]. They used digital cameras to collect the traffic video data from the busiest express ways in Beijing to analyse headway characteristics. According to the results from their study, the log-normal distribution model is a good choice when the traffic is in free flow conditions. Meanwhile, the log logistic distribution model is suitable for headway data in congestion.

Previous studies are mainly based on the entire time headway data collected from a highway/freeway section regardless of considering the vehicle types. They were mainly undertaken under light to medium traffic flow conditions. Furthermore, the influence of vehicle type (heavy vehicles or passenger cars) on the minimum headway requirements is mainly ignored in previous studies. In this paper, headway distributions are analysed and compared for heavy vehicles and passenger cars under heavy traffic conditions. For the time intervals presented in the data, the traffic flow condition for each site reflects Level Of Service (LOS) E which is considered as heavy traffic conditions. The LOS is a qualitative measure which describes the operational conditions within a traffic stream based on service measures such as average speed, travel time, freedom to manoeuvre, traffic interruptions, and comfort and convenience. To accurately evaluate the headway characteristic, different following combinations of heavy vehicles and passenger cars are considered and the time headways are separately evaluated for each combination. These combinations include: passenger car following a passenger car (C-C), passenger car following a heavy vehicle (C-H), heavy vehicle following a passenger car (H-C), and heavy vehicle following a heavy vehicle (H-H). To better analyse headway distributions in the vicinity of heavy vehicles and passenger cars, the headways are evaluated for each car following combination at different traffic flows. Subsequently, simple mathematical models are suggested to estimate the parameters of the headway distributions at different traffic flow rates.

This paper is structured as follows. The following section explains the dataset used in this study. The methodology as well as the appropriate models of headway distributions which are selected for each car following combination (C-C, C-H, H-C and H-H) is explained afterwards. The relationship between the parameters of the headway distributions for different car following combinations is also analysed at different traffic flow rates. The final section summarizes the results of this paper and provides directions for future research.

2. Dataset

The trajectory data used in this study was provided for a highway section in California: Berkeley Highway (I-80). The schematic illustration of this highway section is shown in Figure 1.

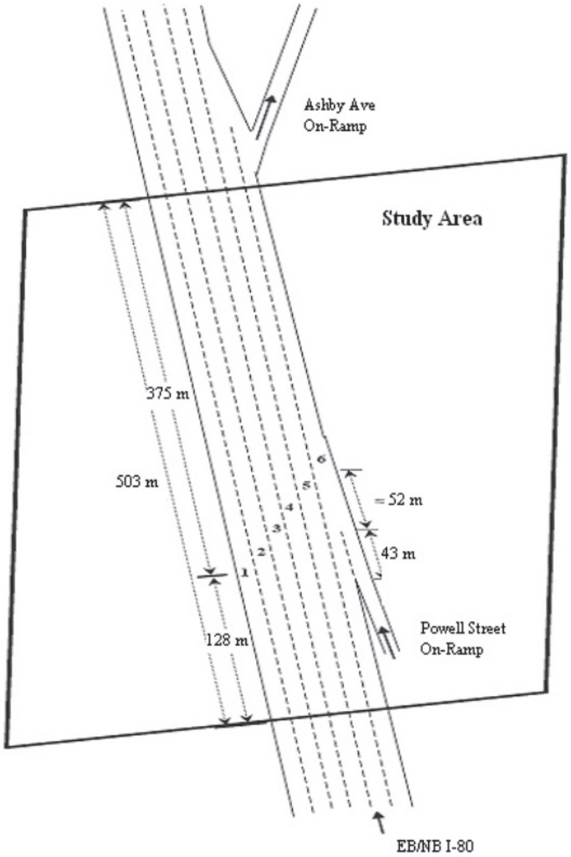

Fig. 1: Schematic illustration of lane configuration for the section of I-80.

The section of I-80 is 503 meters long and comprises five main lanes with one auxiliary lane. There is one on-ramp in this section and one exit off-ramp downstream of the section [30]. There are no lane restrictions for heavy vehicles in this section. The data were collected from 4:00 to 4:15 PM and 5:00 to 5:30 PM using a video capture rate of 10 frames per second. The data was collected using seven video cameras mounted on a 30-story building. The dataset was provided in clear weather, good visibility, and dry pavement conditions. The dataset has classified vehicles as automobiles, heavy vehicles and motorcycles. Table 1 shows the traffic flow parameters for the section of I-80. For the time period that the data was collected, the proportion of heavy vehicles is 4.7%, 3.8% and 2.7% of the total traffic at 4:00 to 4:15 PM, 5:00 to 5:15 PM and 5:15 to 5:30 PM, respectively.

The trajectory dataset used in this study makes it possible to determine the time and space headways between the heavy vehicles or passenger cars and their surrounding vehicles at discrete time points. In this study, the headways are measured as the time between the front bumper of the vehicle (heavy vehicle or passenger car) and the front bumper of the preceding vehicle. Due to the noise in the NGSIM dataset, the data was aggregated at each 0.5 second time interval. Then, the aggregated trajectory data at each 0.5 second time interval (2 observations per second) was used in this study. This is consistent with the previous studies on the NGSIM dataset [31]. According to results from Thiemann et al. [31], aggregating the NGSIM data at each 0.5 second reduces the noise of the data. Meanwhile, the aggregation is weak and maintains the trends in driving behaviour.

Table 1: Traffic flow parameters in the section of I-80.

Time Interval	Traffic Flow (veh/hr)	Speed (km/hr)	Density (veh/km)*	Level Of Service (LOS)
4:00 to 4:05 PM	8436	32.3	261	E
4:05 to 4:10 PM	7968	28.7	278	E
4:10 to 4:15 PM	8028	25.2	319	E
5:00 to 5:05 PM	8124	27.5	295	E
5:05 to 5:10 PM	7752	23.2	334	E
5:10 to 5:15 PM	5988	15.1	397	E
5:15 to 5:20 PM	7836	21.9	358	E
5:20 to 5:25 PM	7284	21.2	344	E
Abstract) PM	6024	15.9	279	E
Total	7493	23.1	324	E

* Density is calculated as the number of vehicles per kilometre length of all lanes.

To analyse the time headways for each combination of vehicles (C-C, C-H, H-C and H-H), all vehicle pairs for each combination were derived from the trajectory data. Table 2 presents the number of vehicle pairs and the number of observations for each car following combination. A total of 204 C-C, 404 C-H, 327 H-C, and 36 H-H were extracted from the trajectory dataset (Table 2). To have an initial comparison of the effect of heavy vehicles and passenger cars on headways, the main statistical characteristics of time headways for different car following combinations are presented in Table 3. According to this table, the smallest time headways are observed when passenger cars following a passenger car (mean value of 1.89 seconds) while the largest time headways are observed when heavy vehicles following a heavy vehicle (mean value of 13.44 seconds).

Table 2: Different following combinations of heavy vehicles and passenger cars.

Number of Vehicles and Observations	Car following combination			
	C - C	C - H	H - C	H - H
Number of Vehicle Pairs	204	404	327	36
Number of Observations*	27509	29145	34525	3134

* Aggregated trajectory data at each 0.5 second time interval (2 observations per second).

Table 3: Headway statistical characteristics for different combinations of heavy vehicles and passenger cars.

Time Headway Characteristics (sec)	C - C	C - H	H - C	H - H
Mean	1.89	2.88	2.23	3.43
Median	1.46	2.27	1.91	3.26
Minimum	0.24	1.01	0.97	1.98
Maximum	6.64	11.92	10.78	13.44

3. Methodology

According to literature, lognormal is a well-known distribution model which is frequently used to represent time headways in many studies. Lognormal distribution is proposed to model time headways under car-following situations [32]. To have a comprehensive analysis and in order to find the most appropriate model for headway distribution, different statistical models were applied to fit the data. Initial results showed that lognormal distribution is an appropriate distribution to model the time headway in this study. This is consistent with the results from majority of the previous studies that strongly suggest lognormal distribution as being the most appropriate distribution for time headway models. Therefore, shifted lognormal distribution is applied in this paper to represent the time headways. The mathematical equation of the shifted lognormal distribution is as follows:

$$f(t \mid \tau, \mu, \sigma) = \frac{1}{\sigma(t-\tau)\sqrt{2\pi}} \times \exp\left(-\frac{(\ln(t-\tau)-\mu)^2}{2\sigma^2}\right); \text{t} > \tau \qquad (1)$$

Where, t is the time headway, τ is the shift value in seconds, and μ and σ are parameters of lognormal distribution known as location and scale parameters, respectively. The two parameters are estimated from the observed data (sample size = n) using Equations 2 and 3.

$$\hat{\mu} = \frac{\sum_{i=1}^{n} \ln(t_i - \tau)}{n} \qquad (2)$$

$$\hat{\sigma} = \left(\frac{\sum_{i=1}^{n} (\ln(t_i - \tau) - \hat{\mu})^2}{n-1} \right)^{\frac{1}{2}} \qquad (3)$$

To identify the shift value of the headway distributions for each car following combination, the lognormal distribution model with shifts ranging from 0.0 to 2.2 seconds (with steps of 0.05 second) are examined. Then, the results from distribution models are comparted with the observed headway distributions. The goodness of fit of the models is checked using Chi-Square test with 95% confidence level. The null hypothesis for each test is presented as follows:

The compatibility hypothesis of time headway distribution with fitted model is rejected (h = 1) or not rejected (h = 0). (4)

In this study, the most appropriate headway distributions for each car following combination are determined using two steps. At the first step, the goodness of fit on the headway distribution is examined for each car following combination (C-C, C-H, H-C and H-H). For that, the p-value parameter is used. In a Chi-Square test with 95% confidence level, larger p-values (p-values should be larger than 0.05) represent a more compatible model. At the second step, the headway distributions are obtained for the headway distribution models for different following combinations of heavy vehicles and passenger cars at different traffic flow rates. For each car following combination, the goodness of fit of headway distributions is examined at traffic flows at each 5-minute time interval (traffic flows presented in Table 1).

4. Results and Discussions

As explained in the previous section, the goodness of fit models on the headway distributions is examined to model the time headway distributions for each car following combination. At the first step, 180 Chi-Square tests are conducted for models with different shifts using SPSS software. For each test, the parameters of the model are estimated from the time headway data. The results of each step are presented in Table 4 which shows the values of ‘h’ for Chi-Square tests on all headways collected for each car following combination. The values of h equal to 1 represent rejection of hypothesis test and its values with zero represent approval of the hypothesis test.

Table 4: Results of Chai-Square test for headway distributions of different car following combinations.

Shift	C - C	C - H	H - C	H - H
0.00	1	1	1	1
0.05	1	1	1	1
0.10	1	1	1	1
0.15	1	1	1	1
0.20	1	1	1	1
0.25	0	1	1	1
0.30	0	1	1	1
0.35	0	1	1	1
0.40	0	1	1	1
0.45	1	1	1	1
0.50	1	1	1	1
0.55	1	1	1	1
0.60	1	1	1	1
0.65	1	1	1	1
0.70	1	1	1	1
0.75	1	1	1	1
0.80	1	1	1	1
0.85	1	1	1	1
0.90	1	1	1	1
0.95	1	1	0	1
1.00	1	1	0	1
1.05	1	0	0	1
1.10	1	0	1	1
1.15	1	0	1	1
1.20	1	0	1	1
1.25	1	1	1	1
1.30	1	1	1	1
1.35	1	1	1	1
1.40	1	1	1	1
1.45	1	1	1	1
1.50	1	1	1	1
1.55	1	1	1	1
1.60	1	1	1	1
1.65	1	1	1	1
1.70	1	1	1	1
1.75	1	1	1	1
1.80	1	1	1	1
1.85	1	1	1	1
1.90	1	1	1	1
1.95	1	1	1	1
2.00	1	1	1	0
2.05	1	1	1	0
2.10	1	1	1	0
2.15	1	1	1	0
2.20	1	1	1	1

As shown in Table 4, the lognormal distribution models are generally well-fitted to headways. For passenger cars following passenger cars (C-C), the lognormal distribution models with shifts ranging from 0.25 to 0.40 seconds are well-fitted while, lognormal distribution models with shifts ranging from 1.05 to 1.20 are fitted to passenger cars following heavy vehicles (C-H). For heavy vehicles following passenger cars (H-C), the lognormal distributions with shifts ranging from 0.95 to 1.05 and for heavy vehicles following heavy vehicles (H-H), shifts from 2.00 and 2.15 are well-fitted. Selected models fitted on headway distribution of different car following combinations are presented in Fig. 2 to 5.

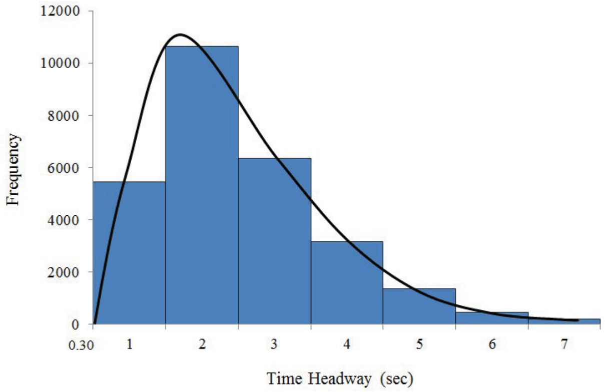

Fig. 2: Time headway distribution of passenger cars following a passenger car (C-C).

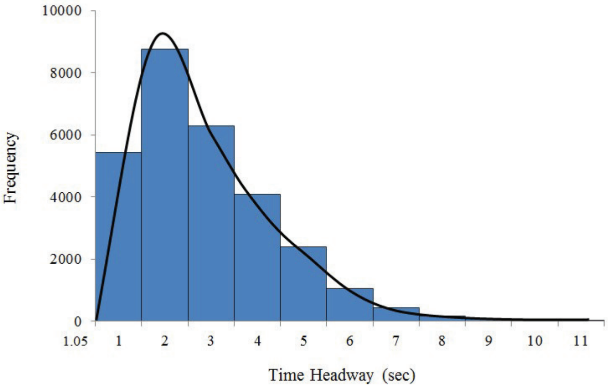

Fig. 3: Time headway distribution of passenger cars following a heavy vehicle (C-H).

According to the results, largest time headways exist when heavy vehicles are following a heavy vehicle. Time headways are also large when heavy vehicles follow a passenger car. This is due to the operational limitations (acceleration, deceleration and manoeuvrability) of heavy vehicles compared to passenger cars. The larger values of headways for passenger cars when following a heavy vehicle compared to the time they are following a passenger car may be due to the safety concerns of the drivers when following a large heavy vehicle. Existence of difference between the headway distribution patterns in vicinity of heavy vehicles and passenger cars will influence the capacity and safety analysis. Ignoring the existence of this difference will cause inaccurate estimation of traffic flow characteristics in urban highways/freeways particularly in roadways with large proportion of heavy vehicles. Difference in headway distribution patterns in vicinity of heavy vehicles and passenger cars influences the minimum safe headways accepted by drivers in vicinity of these two vehicle types and consequently affects the accuracy of safety studies.

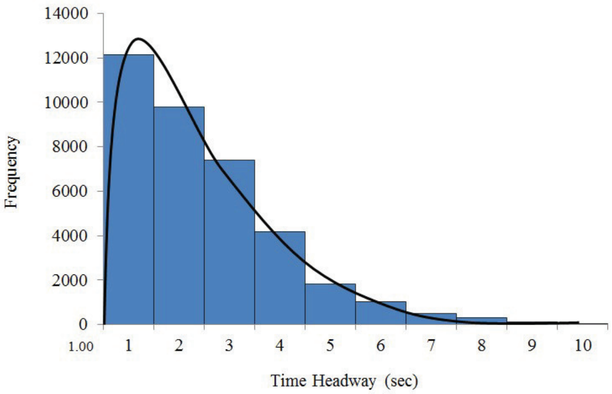

Fig. 4: Time headway distribution of heavy vehicles following a passenger car (H-C).

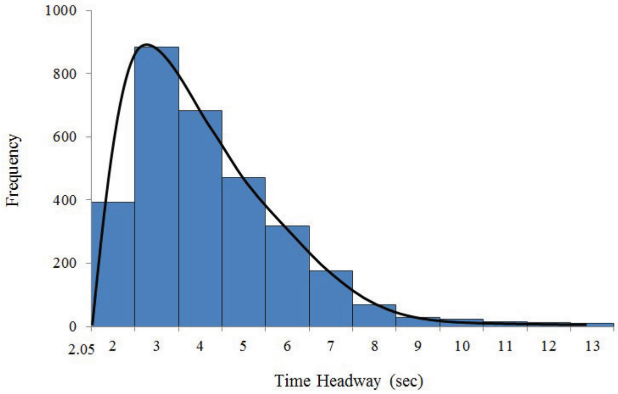

Fig. 5: Time headway distribution of heavy vehicles following a heavy vehicle (H-H).

To further analyse the headway distributions in the vicinity of heavy vehicles and passenger cars, the headways are evaluated at different traffic flows. Therefore, at the second step, the goodness of fit of headway distribution models is examined at traffic flows recorded at each 5-minute time intervals (Table 1). The shifted lognormal models are fitted on headway data for different following combinations of heavy vehicles and passenger cars from traffic flows at each 5-minute time intervals. Estimation results of the parameters of headway distributions are presented in Table 5. In general, lognormal distribution is identified by two parameters including location (μ) and scale (σ). The results of Table 5 show the influence of changes in traffic flows on the parameters of the lognormal distribution. In other words, the influence of changes in traffic flows on the time headway patterns of each car following combination (C-C, C-H, H-C and H-H) are presented in this table.

To better understand the relationship between traffic flows and time headway patterns, and to more accurately estimate the headway distributions for different following combinations of heavy vehicles and passenger cars, the parameters of the headway distributions (μ, σ) can be calculated as a function of traffic flows. Therefore, linear regression models are used to simply estimate the parameters of the headway distributions for each combination (Equations 5 and 6).

$$\mu = a + b \times q \tag{5}$$

$$\sigma = c + d \times q \tag{6}$$

Where, μ is the location of the distribution, σ is the scale of the distribution, q is the traffic flow, and a, b, c and d are parameters.

Table 5: Estimation results of headway distributions for different car following combinations.

Traffic Flow (veh/hr)	C - C		C - H		H - C		H - H	
	μ	σ	μ	σ	μ	σ	μ	σ
5988	2.27	0.68	3.38	0.77	2.67	0.87	4.31	0.78
6024	2.16	0.69	3.24	0.73	2.58	0.92	4.26	0.89
7284	2.08	0.64	3.17	0.78	2.47	0.76	3.58	0.83
7752	1.93	0.67	3.01	0.75	2.39	0.81	3.35	0.74
7836	1.87	0.58	2.89	0.80	2.16	0.79	3.19	0.86
7968	1.72	0.56	2.76	0.78	1.98	0.90	3.13	0.71
8028	1.64	0.62	2.65	0.74	1.85	0.94	3.07	0.77
8124	1.56	0.59	2.57	0.70	1.74	0.78	2.89	0.81
8436	1.41	0.51	2.43	0.71	1.67	0.86	2.74	0.84

The estimation results from the regression modelling are presented in Table 6. By having the parameters of each headway distribution model, time headway distributions can be obtained for different car following combinations at different traffic flow rates. These simple models will assist in more accurately estimating the time headways in vicinity of heavy vehicles and passenger cars. It is noted that the above linear regression models are valid at heavy traffic conditions with small proportions of heavy vehicles (in this study, heavy vehicles comprise 4.7%, 3.8% and 2.7% of the total traffic at 4:00 to 4:15 PM, 5:00 to 5:15 PM and 5:15 to 5:30 PM, respectively). When there is no congestion or when the proportion of heavy vehicles is high, Equations 5 and 6 may not be accurate in estimating the location and scale of the time headway distribution models.

Table 6: Estimation results of headway distributions' location (μ) and scale (σ) parameters.

Headway distribution	μ			σ		
	a	b	R^2	C	d	R^2
C-C	7.2175	-0.0003	0.926	1.6342	-0.0011	0.702
C-H	5.1196	-0.0003	0.913	1.5291	-0.0023	0.684
H-C	4.9857	-0.0005	0.862	1.3957	-0.0094	0.607
H-H	3.0182	-0.0006	0.814	1.1955	-0.0188	0.538

According to the results from Table 6, the location of headway distribution models (μ) which represents the mean value of the headways can be accurately estimated (R^2 values of more than 0.814) for each car following combination. However, the scale parameter (σ) which shows the standard deviation of the time headways can be estimated with lower accuracy (R^2 values of more than 0.538).

5. Conclusions and Future Research Directions

In this paper, headway distributions were analysed under heavy traffic conditions. To comprehensively evaluate the headway characteristic, different following combinations of heavy vehicles and passenger cars were considered and the time headways were separately evaluated for each combination. Those combinations include: passenger car following a passenger car (C-C), passenger car following a heavy vehicle (C-H), heavy vehicle following a passenger car (H-C), and heavy vehicle following a heavy vehicle (H-H). To better analyse the headway distributions in the vicinity of heavy vehicles and passenger cars, the time headways were evaluated at different traffic flow rates. Then, simple mathematical models were suggested to estimate the parameters of the headway distributions at different traffic flow rates for each car following combination.

According to the results from this study, lognormal distribution models were generally well-fitted to time headways. For the passenger cars following either a passenger car (C-C) or a heavy vehicle (C-H), the lognormal distribution models with shifts ranging from 0.25 to 0.40 seconds and lognormal distribution models with shifts ranging from 1.05 to 1.20 seconds were well-fitted, respectively. For heavy vehicles following either a passenger car (H-C) or a heavy vehicle (H-H), the lognormal distributions with shifts ranging from 0.95 to 1.05 and lognormal distributions with shifts from 2.00 and 2.15 were well-fitted. The largest time headways were observed when heavy vehicles follow a heavy vehicle. Time headways were also large when heavy vehicles follow a passenger car. This is due to the operational limitations (acceleration/deceleration and manoeuvrability) of heavy vehicles compared to passenger cars. The larger values of headways for passenger cars following a heavy vehicle compared to the time they follow a passenger car may be due to the safety concerns of the drivers when following a heavy vehicle. Existence of difference between the headway distribution patterns in vicinity of heavy vehicles and passenger cars will influence the capacity and safety analysis. Ignoring the existence of this difference will cause inaccurate estimation of traffic flow characteristics in urban highways/freeways particularly in roadways with large proportion of heavy vehicles or during heavy traffic conditions.

To better understand the relationship between traffic flows and time headway patterns, the parameters of the headway distributions (μ, σ) were calculated as a function of traffic flows. Therefore, linear regression models were used to simply estimate the parameters of headway distributions for each car following combination and at different traffic flow rates under heavy traffic conditions. By having the estimated parameters of each headway distribution model, headway distributions can be obtained for each car following combination at different traffic flow rates. This may assist in more accurately estimating the headways in vicinity of heavy vehicles and passenger cars. Difference in headway distribution patterns in vicinity of heavy vehicles and passenger cars influences the minimum safe headways accepted by drivers in vicinity of these two vehicle types and consequently affects the accuracy of safety studies. Accurate headway distribution models can be used in microscopic traffic simulation tools to generate multi-class vehicles at different lanes, capacity estimation per lane and passenger car equivalent estimation, gap acceptance behaviour analysis and infrastructural design and planning. In addition, having more accurate headway models may be beneficial in understanding the reasons of accidents as well as evaluating policies to enhance traffic capacity and road safety.

In this study, the headway distributions were evaluated based on entire headway data collected from a highway section without separating the data of each lane. However, each lane has different traffic flow characteristics which may influence the time headway distributions. Exclusive analysis of the headway distributions for each lane can be a direction for future research. Furthermore, headway distributions can be evaluated at different congestion levels and with different proportion of heavy vehicles. When there is no congestion or when the proportion of heavy vehicles is high, vehicles may have different headway patterns. Detailed headway distribution analysis may assist in more accurate traffic planning and policy making.

References

[1] Highway Capacity Manual. *Transportation Research Board, National Research Council*. Washington, U.S.A. 2010.

[2] P. G. Michael, F. C. Leeming and W. O. Dwyer. "Headway on urban streets: observational data and an intervention to decrease tailgating". *Trans. Res. F*, vol. 3, pp. 55-64. 2000.

[3] A. Al-Ghamdi. "Analysis of time headways on urban roads: case study from Riyadh". *J. of Trans. Eng.*, vol. 127, pp.289-294. 2001.

[4] M. Brackstone, B. Waterson and M. McDonald. "Determinants of following headway in congested traffic". *Trans. Res. F*, vol. 2, pp. 131-142. 2009.

[5] C. Yusheng, W. Lina, P. Yulong and L. Xianzhang. "Gap acceptance capacity model for on-ramp junction of urban freeway". *J. of Trans. Sys. Eng. and Info. Tech.*, vol.9, pp.116-119. 2009.

[6] S. Moridpour, G. Rose and M. Sarvi. "Effect of surrounding traffic characteristics on lane changing behavior". *J. of Trans. Eng*, vol.136, pp.973-985. 2010.

[7] S. Moridpour, M. Sarvi and G. Rose. "Modeling the lane changing execution of multi class vehicles under heavy traffic conditions". *Trans. Res. Rec., J. of the Trans. Res. Board*, vol.2161, pp.11-19. 2010.

[8] S. M. Abtahi, M. Tamannaei and H. Haghshenash. "Analysis and modeling time headway distributions under heavy traffic flow conditions in the urban highways: case of Isfahan". *Transport*, vol.26, pp.375-382. 2011.

[9] K. Aghabayk, M. Sarvi and W. Young. "Understanding the dynamics of heavy vehicle interactions in car-following". *J. of Trans. Eng.*, vol.138, pp.1468-1475. 2010.

[10] S. K. Dubey, B. Ponnu and S. S. Arkatkar. "Time gap modeling under mixed traffic condition: a statistical analysis". *J. of Trans. Sys. Eng. and Info. Tech.*, vol.12, pp.72-84. 2012.

[11] O. Hagring. "Estimation of parameters in distribution of headways in roundabouts". *J. of Trans. Eng.*, vol.128, pp.403-411. 2002.

[12] H. T. Zwahlen, E. Oner and K. Suravaram. "Approximated headway distributions of free-flowing traffic on Ohio freeways for work zone traffic simulations". *Trans. Res. Rec., J. of the Trans. Res. Board*, vol.1999, pp.131-140. 2007.

[13] P. Dey and S. Chandra. "Desired time gap and time headway in steady-state car-following on two-lane roads. *J. of Trans. Eng.*, vol.135, pp.687-693. 2009.

[14] M. Jakimavičius and M. Burinskienė. "A GIS and multi-criteria-based analysis and ranking of transportation zones of Vilnius city". *Technological and Economic Development of Economy*, vol.15, pp.39-48. 2009.

[15] B. S. Kerner. "Introduction to modern traffic flow theory and control: the long road to three-phase traffic theory", 1st edition, ISBN: 978-3-642-02604-1. 2009.

[16] B. Mesarec and M. Lep. “Combining the grid-based spatial planning and network-based transport planning”. *Technological and Economic Development of Economy*, vol.15, pp.60-77. 2009.

[17] S. Moridpour, M. Sarvi, G. Rose and E. Mazloumi. “Lane-changing decision model for heavy vehicle drivers”. *J. of Int. Trans. Sys.: Tech., Planning, and Operations*, vol.16, pp.24-35. 2012.

[18] W. K. M. Alhajyaseen, M. Asano and H. Nakamura. “Left-turn gap acceptance models considering pedestrian movement characteristics”. *Accident Analysis and Prevention*, vol.5, pp.175-185. 2013.

[19] S. Moridpour, E. Mazloumi and M. Mesbah. “Impact of heavy vehicles on surrounding traffic characteristics”. *J. of Advanced Trans.*, vol.49, pp.535-552. 2015.

[20] T. V. Arasan and R. Z. Koshy. “Headway distribution of heterogeneous traffic on urban arterials”. J. of the Ins. of Eng., vol.84, pp.210-215. 2003.

[21] K. Vogel. “A comparison of headway and time to collision as safety indicators”. *Accident Analysis and Prevention*, vol.35, pp.427-33. 2003.

[22] S. Moridpour, E. Mazloumi, M. Sarvi and G. Rose. “Enhanced evaluation of heavy vehicle lane restriction strategies in microscopic traffic simulation”. *J. of Trans. Eng.,* vol.138, pp.1-7. 2012.

[23] G. Zhang, Y. Wang, H. Wei and Y. Chen. “Examining headway distribution models with urban freeway loop event data”. *Trans. Res. Rec., J. of the Trans. Res. Board*, vol.1999, pp.141-149. 2007.

[24] P. Yi, Y. Zhang, J. Lu and H. Lu. “Safety-based capacity analysis for Chinese highways - a preliminary study”. *IATSS Res.*, vol.28, pp.47-55. 2004.

[25] S. P. Hoogendoom and P. H. L. Bovy. “Estimation and analysis of multilane multiclass headway distribution models”. *Trans. Res. Rec., J. of the Trans. Res. Board*, vol.1646, pp.18-28. 1998.

[26] M. Mei and A. G. R. Bullen. “Lognormal distribution for high traffic flows”. *Trans. Res. Rec., J. of the Trans. Res. Board*, vol.1398, pp.125-128. 1993.

[27] S. Sadeghhosseini. “Time headway and platooning characteristics of vehicles on interstate highways”, PhD. Dissertation, University of Illinois. 2002.

[28] G. H. Bham and S. R. P. Ancha. “Statistical models for preferred time headway and time headway of drivers in steady state car-following”. *App. of Advanced Tech. in Trans.: Proceedings of the Ninth International Conference*, 13-16 August, Chicago, Illinois, USA, 344-349. 2006.

[29] S. Yin, Z. Li, Y. Zhang, D. Yao, Y. Su and L. Li. “Headway distribution modeling with regard to traffic status”. *Intelligent Veh. Sym., IEEE*, 3-5 June, 1057-1062. 2009.

[30] Cambridge Systematics. NGSIM I-80 Data Analysis. Summary Reports, Federal HighWay Administration (FHWA). https://camsys.com/. 2005.

[31] C. Thiemann, M. Treiber and A. Kesting. “Estimating accelerationand lane-changing dynamics from Next Generation Simulation trajectory data”. *Trans. Res. Rec., J. of the Trans. Res. Board*, vol.2088, pp.90-101. 2008.

[32] I. Grenberg. “The log-normal distribution of headways”. *Australian Road Res.*, vol.2, pp.14-18. 1966.