KSCE Journal of Civil Engineering (2024) 28(8):3520-3532
DOI 10.1007/s12205-024-0640-4
pISSN 1226-7988, eISSN 1976-3808
www.springer.com/12205

Transportation Engineering

Analysis of Time Headway Characteristics at the Curbside Bus Stop on Multi-Lane Divided Urban Arterials under Mixed Traffic Conditions

Sruthi Sekhar Pallela[a] **and Arpan Mehar**[a]

[a]National Institute of Technology Warangal, Warangal 506004, India

ARTICLE HISTORY

Received 4 April 2023
Revised 12 September 2023
Accepted 21 February 2024
Published Online 31 May 2024

KEYWORDS

Time headway
Headway distribution
Critical time headway
Capacity
Bus stop
Speed-flow diagram

ABSTRACT

Time headway analysis is crucial in traffic engineering for understanding traffic flow and enhancing safety. Prior studies often neglected the impact of curbside bus stops, but this study explores time headway in vehicular traffic with curbside bus stops, estimating critical time headway using fundamental diagram-derived road section capacity. Field data was collected from various sections, both with and without curbside bus stops, experiencing varying traffic conditions. Headway data analysis showed curve profiles changing due to lane shifts, traffic flow, and interactions between leading and following vehicles. Various factors, including traffic volume, two-wheeler percentage, and lane count, all negatively affected average time headway. In contrast, longer bus dwell times and more heavy vehicles in the traffic stream led to increased time headway across all road sections. A model was proposed to estimate average time headway based on these influencing variables. Moreover, a speed-volume diagram assessed road capacity, revealing critical time headway variations: 0.63 seconds for six-lane divided roads and 1.43 seconds for four-lane divided roads. These differences stemmed from factors including traffic flow, road design, driver behavior, and capacity considerations. The study establishes critical time headway's vital role in improving safety, reliability, and efficiency at curbside bus stops.

1. Introduction

Time headway is a key microscopic parameter in traffic flow theory known as the time gap between two consecutive vehicles crossing a reference line on the roadway. Time headway characteristics are used for the study of capacity, mobility, and safety performance o roadways. The study of time headway distributions is essential for modelling of traffic flow behavior at macroscopic and microscopic levels. Modelling time headway by using standard mathematical distributions is a typical approach suitably applied under homogenous conditions. However, traditional distributions are not usually followed under heterogeneous traffic conditions due to lack of lane discipline and variability of physical and dynamic characteristics of vehicle types. In India, traffic on urban roads is highly heterogeneous that generally influenced by various kinds of side friction factors such as curb side bus stop, on-street parking, lane encroachment, and pedestrian interactions, etc. The curb side bus stop acts as one of the major side friction elements causing an interruption to the smooth flow of traffic. A curb bus stop is a roadway infrastructure where a bus stops to load and unload passengers by occupying certain space within a carriageway lane. The time headway characteristic of vehicular traffic stream changes due to a curb-side bus stop during maneuvering and halting of a bus. The presence of a bus in the outer lane creates a temporary bottleneck at curb-side bus stop that affects the roadway capacity and traffic operational performance.

The current research aims to examine the time headway characteristics of vehicular traffic under both typical traffic and capacity flows scenarios, encompassing curb-side bus stops and its upstream mid-block roadway locations. The study extensively reviewed the literature based on statistical distribution analysis, and capacity analysis under uniformed and mixed traffic flow conditions including the curb side bus stops.

The structure of the paper is organized as follows. The section 1 address the need and scope of the present study. The section 2 discusses relevant studies and highlights gaps in the knowledge along with study objectives. The section 3 provides detailed explanation on the research approach, site selection, data collection

CORRESPONDENCE Sruthi Sekhar Pallela sruthisekhar10@student.nitw.ac.in National Institute of Technology Warangal, Warangal 506004, India

and extraction of necessary data. The section 4 and section 5 present the statistical distribution analysis, fundamental diagram and capacity estimation, model development and validation. The results and discussion based on the study are included as separate section 6. The summary of study, significant findings, limitations, policy implications and directions for future research are also discussed in this section.

2. Literature Review

Time headway distribution has long been studied with the main objectives as to analyse road capacity, and road safety (Al-Ghamdi, 1999). In the early stages of research, headways of vehicles are investigated on highways at the aggregate level for the entire traffic stream. From 1990 to the present, researchers have undertaken investigations to assess the suitability of different single and composite distributions for analyzing time headway data across diverse scenarios, such as multi-lane expressways, multi-lane freeways, multi-lane arterials, and work zones. Most researchers (Kinzer, 1934; Adams, 1936; May, 1990; Hossain and Iqbal, 1999; Al-Ghamdi, 2001; Haryadi and Narendra, 2016), suggested negative exponential distribution for headways under low traffic flow conditions on divided and un-divided urban and suburban roads. Similar results were also reported by (Katti and Phatak, 1985; Mukherjee et al., 1988; Issac and Veeraragavan, 1995; Sahoo et al., 1996; Kumar and Rao, 1998; Arasan and Koshy, 2003) under heterogeneous traffic conditions. However, negative exponential distribution failed to represent traffic flow with shorter headways. On urban arterials, few authors like (Greenberg, 1966; May, 1990; Li et al., 2011; Shoaeb et al., 2021) also suggested Gamma distribution is the best fit on urban undivided two-lane arterials under intermediate traffic flow levels. Al-Ghamdi (2001) proposed Gamma distributions for various levels of traffic flow intensity < 400 vph (vehicles per hour), 400 – 1,200 vph, and >1,200 vph. Jang et al. (2011) proposed that the Johnson SB model provided the most accurate fit for flows ranging from 10 to 14 vehicles per meter (v/m) and 20 to 30 v/m. Additionally, the Johnson SU model was identified as the most suitable fit for traffic flows between 15 and 19 v/m. (Kumar and Chandra, 2001) concluded that Hyperlang distribution effectively represented headway data in scenarios involving mixed traffic conditions and traffic volumes ranging from 900 to 1,600 vph. Recent studies on mixed traffic conditions like (Dubey et al., 2012; Dubey et al., 2013; Sooksan, 2014) suggested Generalized Extreme value distribution as better fit at traffic flow greater than 1,500 vph and Generalized Pareto under traffic flow less than 1,500 vph. Dubey et al. (2012) proposed a few composite models to model time gap data for traffic flow ranging from 1,900 vph to 4,100 vph. For traffic flows as 2,300 vehicles per hour (veh/hr) and as 1,900 veh/hr, the optimal mixture models for modeling time gap data was performed with Weibull + log-normal (WEL) and Weibull + Extreme Value (WEV) distributions respectively. (Suresh and Umadevi, 2014) suggested an Inverse gauss distribution model at the lowest peak hour flow, and Triangular distribution model at the highest peak hour flow. Maurya et al. (2016) investigated time headway distribution by categorizing traffic flow levels into different ranges (0 – 200, 200 – 400, 400 – 600, 600 – 800, 800 – 1,000, and 1,000 – 1,200 PCU/h). The study revealed that the Log-Pearson 3, Burr, Gamma, Weibull distribution, and Inverse Gaussian distributions exhibited good fit to the different flow ranges. Das and Maurya (2017) proposed the use of lognormal and log-Pearson 3 distributions as suitable choices for simulating mixed vehicle type headways on two-lane bi-directional road under a traffic flow of 600 PCU/h. Additionally, on four-lane bi-directional road, log-Pearson 3 and Weibull distributions were deemed suitable. Das and Maurya (2018) concluded that the log-normal distribution is found to be the best fit for urban arterial roads. Yu et al. (2022) concluded that the Burr distribution model fits the best among 18 commonly used distribution models.

As per literature, in addition to traffic volume there are several other factors which affects the time headway distributions of vehicles. One such factor is a lane position (Aydin, 2007; Moridpour and Aliakbari, 2016) analysed the effect of reverse-lane usage on time headways for different lanes at an uninterrupted section of the Izmir outer ring road. Zwahlen et al. (2007) concluded that the headway distributions for different lanes are nearly the same for similar hourly traffic volumes. Abtahi et al. (2011) Explored shifted lognormal distribution models with shifts spanning from 0.135 to 0.27 seconds and 0.495 to 0.75 seconds to be well-suited for describing headways in the passing lane and middle lane respectively. Das et al. (2015) studied the effect of lane position on time headways by grouping into median lane (ML) and shoulder lane (SL). And, Burr distribution is observed as the best fit for the shoulder lane. Weibull and Log-logistic (3P) are observed to fit well for median lane headways. (Yigiter and Tanyel, 2015) categorized and assessed continuous time headways for outer, middle, and inner lanes independently. The lognormal distribution with different shift parameters was recommended to characterize time headways within each lane group. Alhamdany and Albayati (2022) suggested the Pearson 6, inverse Gaussian distribution, and Generalized Pareto distribution are the best fits for left lane, middle lane and right lane respectively, on urban roads in Baghdad. The chosen distributions were employed to create a model using nonparametric regression and Theil's slope estimator method.

The majority of studies focusing on time headway distributions have been conducted within the context of intersections, freeways, highways, and arterials. These studies have primarily centered on either traffic volume or lane position, often under uninterrupted conditions. However, one notable aspect that has often been overlooked is the impact of side friction on these distributions. In this context, Pallela and Mehar (2022) examined the time headway distributions in the inner and outer lanes at a curb-side bus stop. The findings indicated that the time headway distributions for the inner and outer lanes aligned favorably with the Log-logistic and Generalized gamma distributions, respectively. Furthermore, a significant void exists in the current research domain. No prior studies have comprehensively investigated time headway with the impact of diverse roadway and traffic conditions, nor have formulated a predictive model (specifically designed) to estimate time headway accompanied by side frictions in urban traffic conditions. Hence, there is a necessity to have a detailed investigation on time headway characteristics with the influence of side friction such as curb side bus stop. The present study is an endeavor in this direction, aiming to address this research gap.

The study defines specific objectives as to study time headway distributions of traffic stream across travel lanes, different range of traffic flow and the presence of diverse leader and follower pair of vehicles. The also aimed at developing a predictive multiple linear regression model that can estimate time headways of vehicular traffic stream passing through a curb-side bus stop section. And, to determine critical time headways of traffic stream by using capacity of roadway section determined by speed-flow fundamental diagrams.

3. Methodology of the Study

To assess time headway effects at curbside bus stops without designated bus bays. The study employs a methodology identifying study sections through reconnaissance surveys and site visits. Empirical research involves extensive data collection using videography, averaging volume counts, speed, and time headway in 1-minute intervals. Statistical parameters analyze cumulative time headway distributions for goodness-of-fit at a 95% confidence level across various traffic flow levels, lanes, and lead-follower vehicle combinations. The study explores factors influencing time headway characteristics and utilizes predictive modeling techniques to construct a comprehensive model. Fundamental speed-flow diagrams estimate capacity, and critical time headway is determined using the regression model, validated through MAPE values from the speed-flow diagrams.

3.1 Selection of Study Areas

Selected study locations in Hyderabad and Warangal, India, include six-lane and four-lane divided curbside bus stop and mid-block roadway sections. These sections, chosen on flat terrain with a gradient less than ±2%, feature favorable road surfaces, clear lane markings, and no additional disturbances like on-street parking, access points, or encroachments, except for the presence of a curbside bus stop. Fig. 1 displays Google Earth images of two bus stop sections situated on six-lane divided and four-lane divided roads.

The roadway and geometric details of the study locations were collected during field surveys. Table 1 presents data from four locations featuring a bus stop and mid-block (upstream side). Fig. 2 illustrates a detailed drawing of the roadway at a bus stop section.

3.2 Field Data Collection and Extraction

Field traffic data were collected simultaneously at four bus stop and upstream mid-block road sections using video cameras for a 6-hour period from 7 am to 1 pm. The minimum sample size was determined, capturing traffic flow data on weekdays (usually Fridays) and weekends to encompass complete traffic behavior at curbside bus stops. A reference line on the pavement guided

(a) (b)

Fig. 1. Snapshot of Study Locations at Hasthinapuram and Bheemaram Roads: (a) Hasthinapuram (Six-lane divided road), (b) Bheemaram (Four-lane divided road)

Table 1. Inventory Survey Details of Study Locations

No.	Study Locations	No. lanes	Inner *LW (m)	Middle LW (m)	Outer LW (m)	*SW (m)	*BSL (m)
1.	Bheemaram	2	3.5	-	3.5	0.50	6.31
2.	Hasthinapuram	3	3.6	3.6	2.6	1.00	6.00
3.	Karmanghat	3	3.4	3.4	3.6	2.50	6.50
4.	Fbb showroom	2	3.6	-	3.5	1.00	7.00

*LW-Lane width, *SW-Shoulder width, *BSL-Bus shelter length

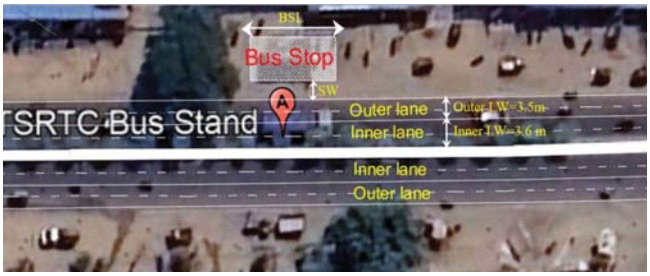

Fig. 2. Roadway Details at Bheemaram Bus Stop

the study and with two elevated vantage points equipped with video cameras one for each section. Cameras were strategically placed to capture precise moments when both front and rear ends of vehicles crossed the reference line. The mid-block road section located approximately 250 m upstream from the bus stop was chosen for data collection. Data were collected on four-lane divided roads at Bheemaram and the FBB showroom locations in February 2022, as well as on six-lane divided roads in Hasthinapuram and Karmanghat in May 2022 under sunny weather condition. The survey covered a range of traffic flow data to ensure diverse vehicle interactions. MPC-HC video player extracted traffic volume, vehicle composition, time headway, and individual vehicle speeds. As free-driving conditions were absent during survey hours the extracted data was filtered to exclude instances like time headway exceeding 10 seconds or less than 0 seconds. Conservation laws apply due to the absence of access points between curb-side bus stops and upstream mid-block sections maintaining unchanged traffic volume and vehicle composition. Table 2 displays vehicle composition and traffic volume for all locations.

Traffic volume obtained in vehicle/hour are converted into PCU/hour by calculating standard equivalence factor (SEF) using PCU value of each vehicle type as suggested in Indo-HCM (2017). The Eq. (1) is used for finding SEF to convert traffic volume in terms of PCUs.

$$SEF = \sum_i PCU_i * P_i, \tag{1}$$

where SEF = Standard Equivalence Factor, PCU = Passenger Car Unit (as per Indo-HCM 2017), P_i = Percentage vehicle composition, i = vehicle type.

4. Field Data Analysis

Lane preference (LP) is determined by analyzing the percentage of vehicles in each lane. Figs. 3 and 4 illustrate the estimated lane preference percentages at bus stop and upstream mid-block sections for four-lane and six-lane roadway locations, respectively.

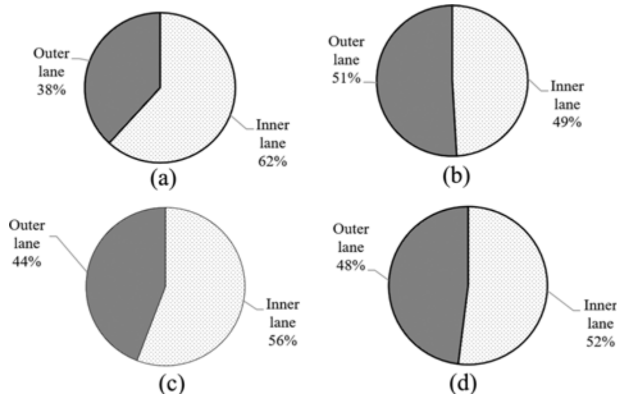

Fig. 3. Lane Preference at Four-Lane Divided Section: (a) Bheemaram Bus Stop, (b) Bheemaram Mid-Block, (c) Fbb Showroom Bus Stop, (d) Fbb Showroom Mid-Block

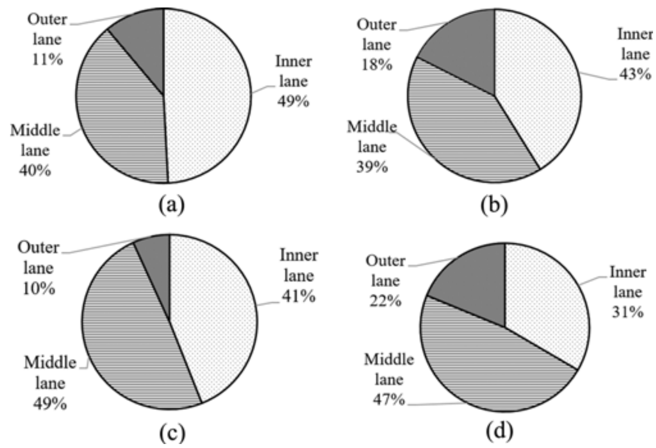

Fig. 4. Lane Preference at Six-Lane Divided Section: (a) Hasthinapuram Bus Stop, (b) Hasthinapuram Mid-Block, (c) Karmanghat Bus Stop, (d) Karmanghat Mid-Block

The bus stop's presence causes side friction prompting vehicles to shift to inner lanes. On six-lane roads, the percentage of vehicles in outer lanes is significantly lower due to the existence of a middle lane. Lane distribution at bus stop sections reveals that over 50% of vehicles prefer inner lanes in four-lane divided sections, while over 80% opt for inner and middle lanes in six-lane divided sections. Vehicle wise speed data were extracted by considering a trap length of 27 m (Traffic engineering handbook, Institute of

Table 2. Vehicle Composition at the Bus Stop Sections

Location	Traffic volume (PCU/hr)	Vehicle composition (%)						
		Two-wheeler (2W)	Three-wheeler (3W)	Car	Bus	LCV	HV	SMV
Bheemaram	1801	65.3	14.5	15.1	1.7	2.2	1.2	0.0
Hasthinapuram	2787	56.8	20.1	16.8	1.6	4.1	0.2	0.3
Karmanghat	3644	65.5	10.1	17.8	1.3	3.5	1.7	0.0
FBB showroom	1508	66.7	19.7	9.9	1.0	2.0	0.0	0.7

Table 3. Percentage Speed Reduction due to Curb-Side Bus Stop

Location	Lane	Average stream speed (Kmph)		Speed reduction (%)
		Mid-block	Bus stop	
Bheemaram	Carriageway	33.29	25.77	22.57
	Inner	34.95	27.82	20.39
	Outer	31.69	22.20	29.96
Fbb showroom	Carriageway	29.90	25.50	17.25
	Inner	35.80	29.70	20.53
	Outer	32.00	26.30	21.67
Hasthinapuram	Carriageway	42.06	35.42	15.79
	Inner	48.32	40.21	16.80
	Middle	39.33	32.18	18.19
	Outer	31.34	21.80	30.44
Karmanghat	Carriageway	40.76	34.27	15.93
	Inner	45.47	40.90	10.03
	Middle	38.11	32.78	13.99
	Outer	30.70	22.44	26.91

Traffic Engineering, 1965) by noting down the entry and exit timestamps. The weighted average speed of vehicular streams is calculated every 5 minutes using Eq. (2). Speeds at upstream mid-block and bus stop sections are classified based on vehicle position across roadway lanes. The percentage reduction in speed at the bus stop compared to the upstream mid-block section is provided in Table 3.

$$V_{ag} = \sum_i v_i * p_i , \quad (2)$$

where, V_{avg}= Weighted average stream speed (Kmph), i = vehicle types in the traffic stream, v = Speed of each vehicle type (Kmph), p = proportion of each vehicle type

Significant speed reduction occurs at bus stop sections compared to mid-block sections. The presence of a bus induces increased lane-changing further contributing to speed reduction. The outer lane of a four-lane divided road section experiences the highest speed reduction due to side friction caused by the bus stop.

Continuous time stamps were noted whenever a vehicle crosses the reference line. Time headway is calculated as the difference between the times of two successive vehicles crossing the reference line. Descriptive statistics for time headway (TH) data are presented in Table 4.

Mean time headway values are higher at the bus stop than the upstream mid-block roadway, attributed to interruptions caused by the bus when stopped on the carriageway. Interruption levels vary based on factors such as dwell time, bus frequency, and bus bunching ratio, indicating how long the bus is stopped, how many buses stop within a given interval, and the frequency of bus bunching on a specific route.

Dwell time data calculated as the difference between bus arrival and departure time stamps, reflects the duration of road interruption. Bus frequency, measured as Bus/hr, indicates the total buses stopping at the bus stop. Bus bunching occurs when two or more buses arrive almost simultaneously, impacting passenger waiting times. The Bus Bunching Ratio (BBR), calculated as the ratio of the leading bus's headway to the trailing bus's headway, signifies the occurrence of bus bunching. Table 5 presents details of dwell time, bus frequency, and bus bunching ratio. Fig. 5 illustrates distribution profiles of dwell time for various bus stop locations based on frequency.

In practice, a BBR of greater than 1 is not desirable, as it may lead to service disruptions and delays for passengers. A relatively lower bus bunching ratio is observed where the bus frequency is more and vice-versa. While higher bus frequency can help to reduce the likelihood of bus bunching, other strategies may also be necessary to effectively manage this phenomenon and improve the quality of service for passengers.

Table 4. Descriptive Statistics of Time Headway at Selected Locations

Location	Section	Mean TH (s)	Median TH (s)	SD*
Bheemaram	Mid-block	1.27	0.98	1.09
	Bus-stop	1.38	1.06	1.15
Hasthinapuram	Mid-block	0.89	0.64	0.87
	Bus-stop	0.94	0.72	0.92
Karmanghat	Mid-block	0.63	0.45	0.54
	Bus-stop	0.67	0.50	0.54
FBB showroom	Mid-block	1.02	0.72	0.97
	Bus-stop	1.12	0.80	1.05

SD*-Standard deviation

Table 5. Average Dwell Time and Bus Frequency at the Bus Stop

Location	Average dwell time(s)	Bus frequency (Bus/hr)	Bus bunching ratio (BBR)
Bheemaram	19.58	25	0.60
Hasthinapuram	10.75	29	0.40
Karmanghat	17.27	36	0.31
FBB bus stop	12.48	18	0.89

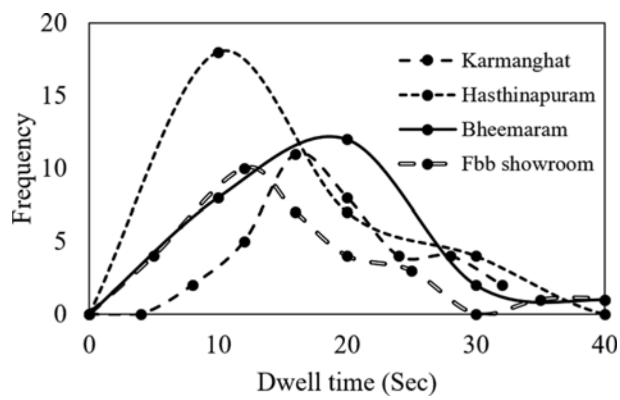

Fig. 5. Dwell Time Profiles of Bus at Bus Stop Sections

5. Time Headway Analysis

Understanding the general traffic flow on road sections requires knowledge of vehicle distribution patterns. Time headway statistical distribution analysis was conducted at a 95% confidence interval, determining the best-fit distribution through the K-S goodness-of-fit test. The analysis of headway data, considering travel lanes and traffic volumes, is detailed below.

5.1 Effect of Travel Lane on Time Headway Distribution

Time headway distribution for each travel lane was analyzed using the 50 – 50 rule with data collected at mid-block and bus stop locations. The best-fitted distribution was identified through the K-S goodness-of-fit test, and relevant parameters (α = shape, β = scale, and γ = location) were estimated using the maximum likelihood method. The shape parameter defines the distribution curve's shape, while the scale parameter influences its spread, allowing customization to match field data variability. Location parameter determines the horizontal shift or location of a probability distribution along the x-axis (Kota and Mehar, 2022). The results of the distribution analysis along with the estimated parameters are shown in Table 6.

Various distribution types fit well across lanes at selected locations due to differing speeds. Matching the shape parameter to time headway characteristics improves traffic flow models. The shape parameter varies significantly: 1.9 to 3.2 seconds for inner lanes vs. middle and outer lanes at bus stops. Typically zero for exponential distributions, its increase signals deviation due to outer lane blockages. Lane-specific analysis is crucial. Log-logistic and log-normal distributions are best for inner and outer lanes at bus stops.

5.2 Effect of Traffic Flow on Time Headway Distribution

Changing traffic flow affects time headway, which varies over time, making a single distribution insufficient. Analysis at different traffic volume levels is necessary. Time headway data from both four-lane and six-lane roads, classified by flow levels, showed decreasing mean and variance with higher traffic volumes. Descriptive analysis results and fitted headway distribution for

Table 7. Descriptive Statistics of Time Headway for Various Flow Ranges

Flow range (PCU/hr)	Mean(s)	Variance	Best-fitted distribution
500 – 1000	1.85	2.90	Gen. Gamma[1]
1000 – 1500	1.56	2.30	Gen. Gamma
1500 – 2000	1.39	2.30	GEV[2]
2000 – 2500	1.13	1.06	GEV
2500 – 3000	0.97	0.85	GEV
3000 – 3500	0.86	0.70	GEV
3500 – 4000	0.75	0.48	Wakeby
4500 – 5000	0.70	0.44	Wakeby
5000 – 5500	0.64	0.30	Wakeby

[2]GEV-Generalized Extreme value, and [1]Gen. Gamma-Generalized gamma

Table 6. Best Fitted Distribution and Parameters for Each Travel Lane

Section	Lane	Best fitted distribution	Static value	Critical value	Estimated parameters
Bheemaram bus stop	Inner	Log-Logistic	0.015	0.036	α = 1.90, β = 1.73, γ = -0.02
	Outer	Log normal	0.022	0.046	α = 0.94, β = 0.95
Bheemaram mid-block	Inner	Pearson 6	0.020	0.041	α_1 = 4.18, α_2 = 3.01, β = 1.82, γ = -0.136
	Outer	Wakeby	0.016	0.041	β = 2.97, α = 3.94 , β = 2.06, α = 0.11, γ = -0.10
Hasthinapuram Bus stop	Inner	Pearson 6	0.023	0.026	α_1 = 3.23, α_2=2.84, β =1.178
	Middle	Pearson 6	0.023	0.028	α_1 = 2.48, α_2 = 3.65, β = 2.679
	Outer	Gen. Pareto	0.025	0.054	α = 0.09, β =7.48, γ = 0.53
Hasthinapuram Mid-block	Inner	Wakeby	0.014	0.027	β_1 = 3.87, α_1 = 10.38, β_2 = 1.56, α_2 = 0.13, γ = -0.13
	Middle	Lognormal	0.019	0.027	α = 1.811, β = 0.525, γ = 0
	Outer	Johnson SB	0.022	0.042	α_1 = 2.00, α_2 = 0.82, β = 41.5, γ = -0.098
Karmanghat Bus stop	Inner	Log-Logistic	0.014	0.024	α = 2.06, β = 1.34, γ = -0.08
	Middle	Wakeby	0.009	0.022	β_1 = 1.73, α_1 = 4.65, β_2=1.07 α_2 = 0.10, γ = 0.01
	Outer	Log normal	0.020	0.050	α = 1.09, β = 1.42, γ = -0.17
Karmanghat Mid-block	Inner	Log-normal	0.012	0.028	α = 2.99, β = 0.54, γ = -0.11
	Middle	Burr	0.016	0.023	α = 2.82, β = 1.50, γ = 2.78
	Outer	Wakeby	0.012	0.034	β_1 = 2.55, α_1 = 8.29, β_2 = 2.48, α_2 = 0.19, γ = 0.11
Fbb showroom Bus stop	Inner	Log-Logistic	0.029	0.0330	α = 2.20, β = 1.41
	Outer	GEV	0.021	0.0250	α = 0.54, β = 1.17, γ = 1.39
Fbb-Showroom Mid-block	Inner	Log-Normal	0.034	0.041	α = 1.00, β = 0.315, γ = -0.00
	Outer	Johnson SB	0.023	0.044	α_1 = 4.41, α_2 = 1.17, β = 125.1, γ = -0.18

α- Shape parameter, β- Scale parameter, and γ- Location parameter

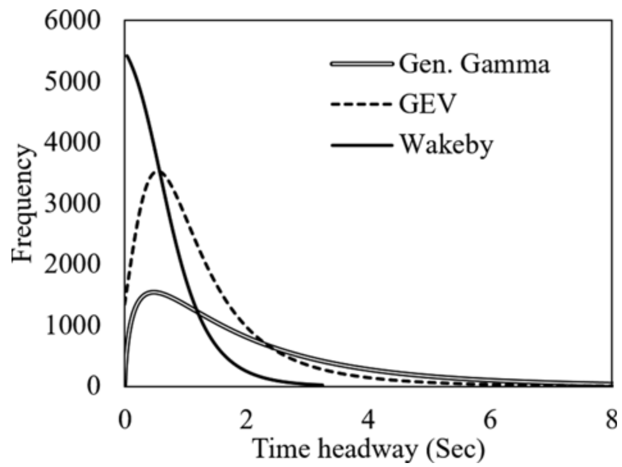

Fig. 6. Best Fitted Time Headway Distribution for Different Flow Ranges

various traffic volumes are in Table 7 and Fig. 6.

Under varying traffic volume levels (500 – 1,500 PCU/hr, 1,500 – 3,500 PCU/hr, and >3,500 PCU/hr), time headway data is best fit with Generalized Gamma (Gen. Gamma), Generalized Extreme Value (GEV), and Wakeby distributions, respectively. Results indicate significant influence of traffic volume on vehicle headway at the bus stop. Table 8 presents the Probability Density Function (PDF) for the best-fitted distribution based on flow and lane position.

5.3 Effect of Leader and Following Vehicle Pairs on Time Headway

Pair-wise headway data analysis investigates the influence of one vehicle type on others. Studying the interaction between leaders and followers at bus stop sections involves identifying vehicle

Table 8. PDF for Best Fitted Distribution (References) at Different Lane Positions and Flow Levels

Distribution	PDF ($f(x)$)
Lognormal (Das and Maurya, 2018)	$f(x) = \dfrac{\exp\left(-\frac{1}{2}\left(\frac{\ln(x-\gamma)-\mu}{\sigma}\right)^2\right)}{(x-\gamma)\sigma\sqrt{2\pi}}$
Gamma (Al-Ghamdi, 2001)	$f(x) = \dfrac{(x-\gamma)^{\alpha-1}}{\beta^{\alpha}\Gamma(\alpha)}\exp(-(x-\gamma)/\beta)$
Burr (Das et al., 2015)	$f(x) = \dfrac{\alpha\kappa\left(\frac{x-\gamma}{\beta}\right)^{\alpha-1}}{\beta\left(1+\left(\frac{x-\gamma}{\beta}\right)^{\alpha}\right)^{\kappa+1}}$
Log-logistic (Pallela and Mehar, 2023)	$f(x) = \dfrac{\alpha}{\beta}\left(\dfrac{x-\gamma}{\beta}\right)^{\alpha-1}\left(1+\left(\dfrac{x-\gamma}{\beta}\right)^{\alpha}\right)^{-2}$
GEV (Pallela and Mehar, 2022)	$f(x) = \begin{cases} \frac{1}{\sigma}\exp-\left((1+\kappa z)^{\frac{-1}{\kappa}}\right)(1+\kappa z)^{-1-\frac{1}{\kappa}} & \kappa \neq 0 \\ \frac{1}{\sigma}\exp(-z\ \exp(-z)) & \kappa = 0 \end{cases}$
Generalized Pareto (Dubey et al., 2012)	$f(x) = \begin{cases} \frac{1}{\sigma}\left(\left(1+\kappa\left(\frac{x-\mu}{\sigma}\right)^{-1-\frac{1}{\kappa}}\right)\right) & \kappa \neq 0 \\ \frac{1}{\sigma}\exp\left(-\frac{(x-\mu)}{\sigma}\right) & \kappa = 0 \end{cases}$
Johnson SB (Jang et al., 2011)	$f(x) = \dfrac{\delta}{\lambda\sqrt{2\pi}z(1-z)}\exp\left(-\frac{1}{2}\left(\gamma+\delta\ln\left(\frac{z}{1-z}\right)\right)^2\right)$
Pearson VI (Alhamdany and Albayati, 2022)	$f(x) = \dfrac{\frac{(x-\gamma)^{\alpha_1-1}}{\beta}}{\beta B(\alpha_1\alpha_2)\left(1+\frac{(x-\gamma)}{\beta}^{\alpha_1+\alpha_2}\right)}$
Wakeby (Zhang et al., 2018)	$f(x) = \dfrac{\alpha}{\beta}\left(1-(1-F)^{\beta}-\dfrac{\gamma}{\delta}(1-(1-F)^{-\delta})\right)$

pairs, estimating their mean headway, and comparing it to relative time headways of follower vehicle types. Fig. 7 illustrates the mean time headways with varying leader and follower vehicle pairs.

A following vehicle with poor operating characteristics maintains a larger gap from the leading vehicle, leading to increased headway values. For instance, Two-wheelers have minimum time headway when following a Two-wheeler leader, while maximum headway occurs when following Bus or Heavy Commercial Vehicle (HCV) leaders with poor dynamics. Larger leading vehicles also result in increased headway as following vehicles maintain larger gaps.

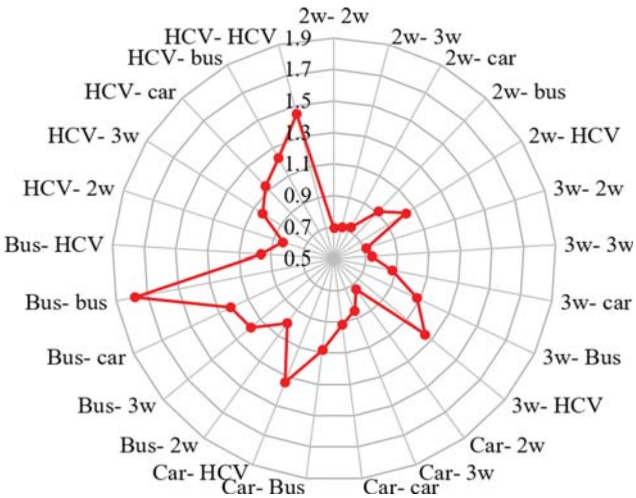

Fig. 7. Mean Time Headway for Varying Leaders and Followers

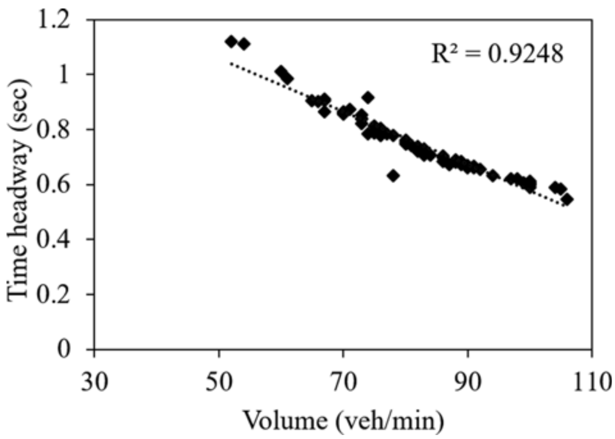

Fig. 8. Effect of Traffic Volume on Time Headway at the Bus Stop

5.4 Modelling of Time Headway at the Bus Stop

A multiple linear regression model identifies variables influencing time headway, examining their correlation to select significant factors. The time headway data was correlated with traffic volume and result is plotted in Fig. 8.

At higher volumes, drivers maintain shorter time headways for traffic flow, while at lower volumes, longer gaps are kept for maneuverability. The percentage of Two-wheelers (2W) and Heavy vehicles (HV) notably influences average time headway. Two-wheelers exhibit the smallest gap at lower speeds due to size and maneuverability, while Heavy vehicles maintain larger gaps due to poorer dynamics, resulting in increased time headways. Figs. 9(a) and 9(b) depict the analyzed relationship between time headway and the percentage of vehicles.

Dwell time at a bus stop on the carriageway is obtained to gauge its impact, disrupting traffic flow as other vehicles change lanes. Longer average dwell times correlate with increased time headway values, signifying greater traffic flow interruption. Fig. 10 collectively presents the observed time headway data at various dwell times for all bus stop sections.

reveals that an increase in lanes allows more vehicles to pass the reference line simultaneously, maintaining lower time headways. Fig. 11 illustrates a larger variation within quartiles at four-lane divided sections compared to six-lane divided sections.

Multiple linear regression analysis (MLR) develops a mathematical model predicting time headway of following vehicles based on traffic and roadway conditions. Time headway serves as the response variable, while predictors include volume, percentage of Two-wheelers and Heavy vehicles, dwell time, and number of lanes. A correlation matrix highlights high correlation values between each predictor variable and the response variable, as displayed in Table 9.

Volume, percentage of Two-wheelers, and number of lanes

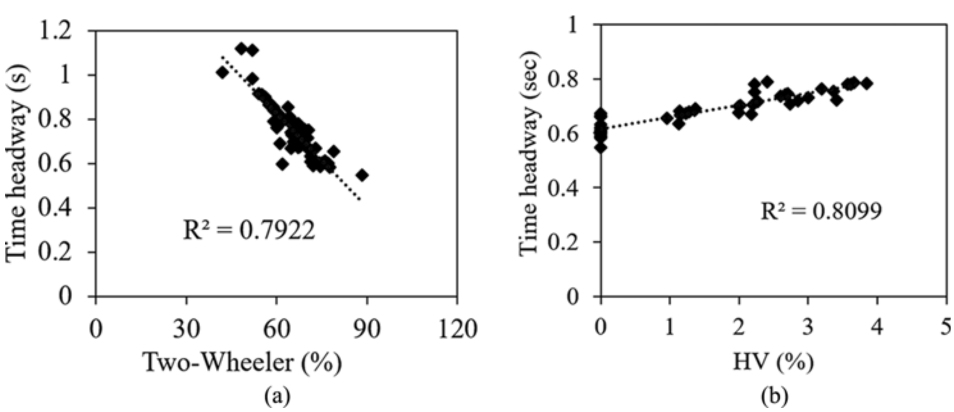

Fig. 9. Effect of Composition on Time Headway at the Bus Stop: (a) Percentage of Two-Wheeler, (b) Percentage of HV

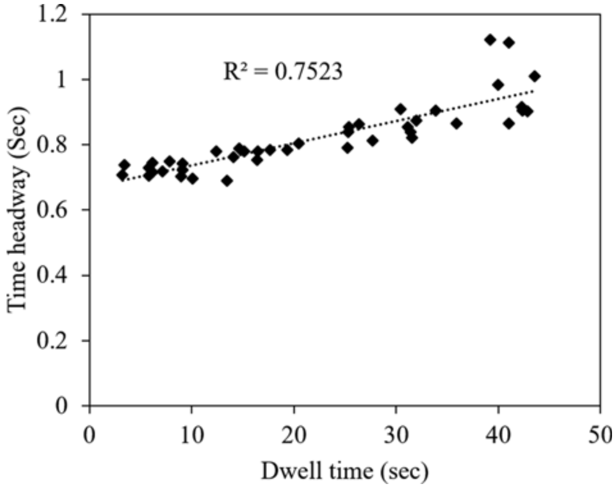

Fig. 10. Effect of Dwell Time on Time Headway at the Bus Stop

Table 9. Correlation Matrix with Predictor Variables

	TH	Q	P_{2w}	D_t	N_L	P_{Hv}
TH	1					
Q	-0.88	1				
P_{2W}	-0.52	0.29	1			
Dt	0.57	-0.33	-0.20	1		
N_L	-0.77	0.25	0.11	0.01	1	
P_{HV}	0.65	-0.30	-0.11	0.26	-0.30	1

where, TH is time headway in seconds, Q is flow in vehicle/min, P2W is the percentage of Two-wheeler, D_t is dwell time in seconds, N_L is the number of lanes and P_{HV} is the percentage of heavy vehicles.

show negative correlations, while Bus dwell time and percentage of Heavy Vehicles (HV) exhibit positive correlations with average time headway. There is nearly no correlation found among the independent variables. Field data collected on locations 1, 2, and 3 (Bheemaram, Hasthinapuram, and Karmanghat) are used for model development. The expression of the developed MLR model is given by Eq. (3).

$$TH = 3.309 - 0.013 \times Q - 0.008 \times P_{2w} + 0.015 \times D_t - 0.452 \times N_L + 0.014 \times P_{HV} \quad (3)$$

This equation is only valid for a high proportion of Two-wheelers (say >50%) and for a very low percentage of Heavy vehicles (say <2%). The t-statistic and p-values of model coefficients are shown in Table 10. The values of the t-statistic are greater than 1.96 and the p-value is less than 0.05 indicating that the variables considered are significant.

5.5 Validation of the Model

The RMSE value and MAPE estimated for validation are 0.139 s and 2.30% respectively. Model validation used data from a four-lane divided section near the FBB showroom bus stop, discussed previously. A 45° line chart (Fig. 12) compared predicted and observed values, showing a realistic match. A Chi-square test with a p-value of 0.02 (<0.05) confirmed goodness of fit. Mean Absolute Percentage Error (MAPE) was 2.30%, computed by summing absolute errors and dividing by the sample size. Root Mean Square Error (RMSE) was 0.139 s, calculated as the square root of the average squared differences between predicted and observed values during validation.

Table 10. Results of MLR Analysis with t-Statistic and p-Value

Model	t-value	p-value
(constant)	30.632	0.000
Q	-2.737	0.007
P_{2w}	-4.412	0.000
D_t	19.697	0.000
N_L	-27.422	0.000
P_{HV}	3.944	0.000

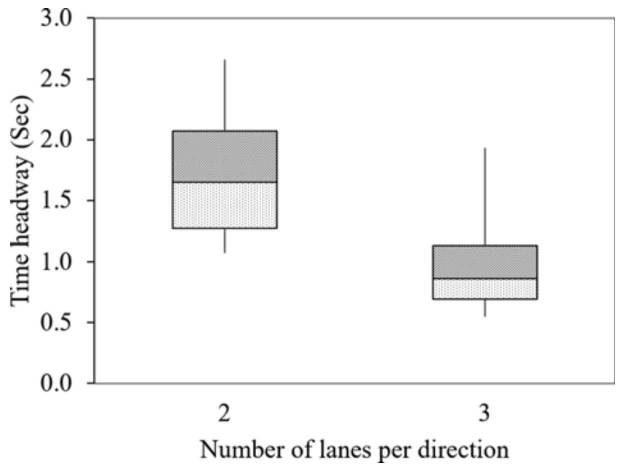

Fig. 11. Effect of Number of Lanes on Time Headway at the Bus Stop

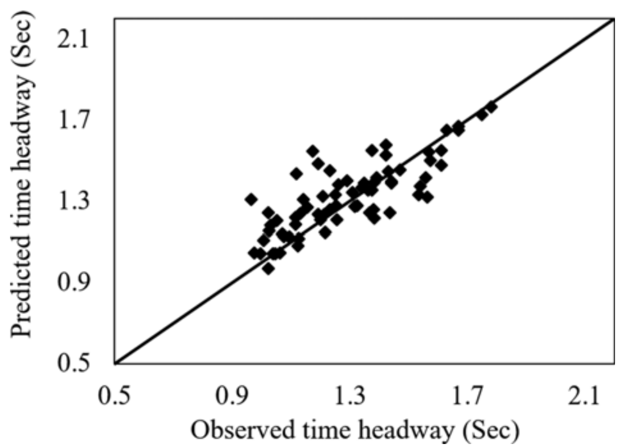

Fig. 12. Validation of the Proposed Model for Estimating Time Headway

5.6 Development of Speed-Volume Relationship

The traffic flow values as obtained for every one minute interval are converted to PCU/hr using (Indo-HCM, 2017) guidelines. The obtained volume is further summed up to estimate total 5-minutes flows. Weighted average stream speed is estimated for same interval of flow observation. Speed-flow relationship is

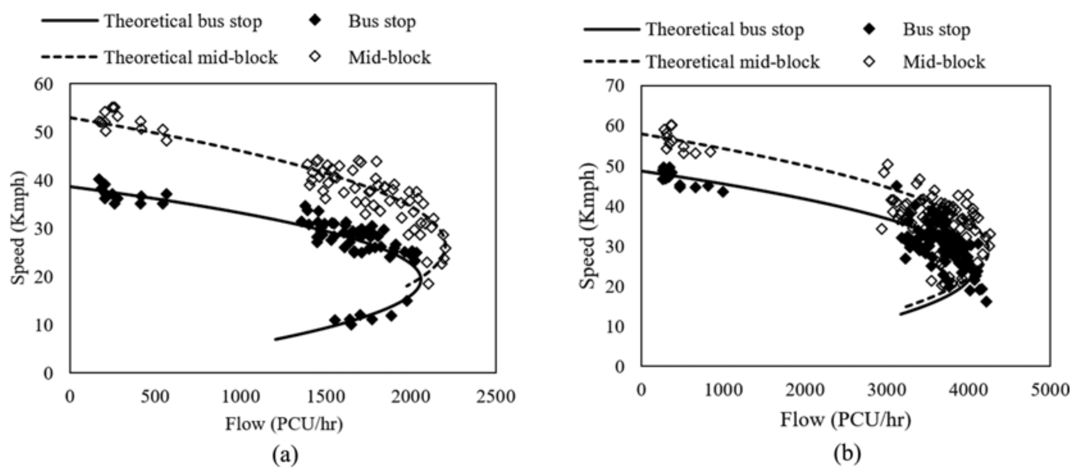

Fig. 13. Speed-Flow Diagram at Bheemaram and Karmanghat Locations: (a) Bheemaram (Four-lane divided), (b) Karmanghat (Six-lane divided)

Table 11. Capacity by Using Speed-Flow Diagram at All Locations (PCU/hr)

Location	Section	Capacity (PCU/hr)
Bheemaram	Bus stop	2060
	Mid-block	2204
Hasthinapuram	Bus stop	3332
	Mid-block	3538
Karmanghat	Bus stop	4059
	Mid-block	4243
FBB Showroom	Bus stop	2372
	Mid-block	2558

developed after obtaining hourly traffic volume and average stream speed for each location selected in the study. For instance, speed-flow diagram using the data collected at the Bheemaram and Karmanghat locations are shown in Fig. 13. The capacity of each section is determined on speed volume curve by superimposing theoretical Greenshields curve. The capacity values obtained from speed volume diagram for all other sections are given in Table 11.

Capacity values of bus stop sections are compared to their upstream mid-block sections, revealing capacity reductions ranging from 4.33% to 7.27%. The lowest reduction occurs at Karmanghat. These capacity values are used to determine the mean critical time headway of the vehicular stream, employing traffic volume at capacity from speed-volume curves in Eq. (3) of the headway model. For example, the maximum flow at the FBB showroom bus stop is 55.08 veh/min, derived from the capacity of 2372 PCU/hr. Other model input parameters, such as vehicle types, dwell time, and lane count, are based on average field location values. The average critical time headway values obtained for all bus stop sections are given in Table 12. For validating the results, predicted critical time headway values are compared with the average time headways calculated at capacity level of volume Q_{max} using a basic relation between flow and time headway. The comparison of critical time headway obtained from two methods

Table 12. Comparison of Mean Time Headways at Capacity for Bus Stop

Bus stop section	Critical Mean Time headway (Sec)		Absolute percentage error (%)
	Developed time headway Model	$h = \frac{3600}{Q_{max}}$	
Bheemaram	1.43	1.32	7.47
Hasthinapuram	0.98	0.90	8.07
Karmanghat	0.63	0.64	2.31
Fbb Showroom	1.25	1.35	8.12

are given in Table 12.

Absolute percentage errors (APE) and mean absolute percentage errors (MAPE) are calculated for statistical comparison. APE values range from 2.31% to 8.12%, ensuring accurate critical time headway determination. MAPE stands at 6.49%, indicating the model's capability to estimate mean time headway at capacity for similar bus stop sections without field data.

6. Results and Discussions

The present study analyzes the statistical time headway distributions of vehicles to gain insights into traffic stream behavior across the travel lanes and traffic flow levels. The investigation is conducted under diverse traffic flow conditions, specifically focusing on bus stop sections and upstream mid-block roadway segments. Findings of the study indicates, vehicles tend to exhibit distinct time headway patterns at bus stop as compared to upstream mid-block segments.

Under low to moderate flow range, the results from present study are in line with the (Al-Ghamdi, 2001) who also suggested Gamma-based distributions. Das and Maurya (2018) deviates by using a log-normal distribution, which may indicate different underlying traffic dynamics. At moderate to high flow levels, the present study's choice of Generalized Extreme Value distribution aligns with (Dubey et al., 2012), showcasing the consistency of distribution selection for higher traffic flow ranges. The present study introduces the Wakeby distribution for very high flow rates, suggesting its effectiveness in addressing extreme traffic conditions. But, at same flow levels (Dubey et al., 2012) uses mixed distributions. In the inner lane, both the present study and (Das et al., 2015) utilize the Log-Logistic distribution. This consistency suggests that the Log-Logistic distribution may effectively model time headways in inner lanes, highlighting its suitability for this specific lane position. While (Abtahi et al., 2011), used a shifted exponential distribution with shifts ranging from 0.135 to 0.27 for inner lane. The middle lane appears to have a more diverse range of distributional choices, with (Abtahi et al., 2011; Alhamdany and Albayati, 2022) and the present study each selecting different distributions. These differences suggest that the choice of distribution may vary depending on factors specific to middle lane traffic patterns. Similarly, differences in distribution selection for the outer lane among the previous studies and present study underscore the variability and complexity of traffic behavior in this position.

Traditionally, time headway is only related with capacity of roadway. The developed model in the present study integrates a range of factors, including vehicle types, roadway conditions, dwell times, and traffic volumes, to provide accurate predictions of time headway. Model developed is validated by using p-value, MAPE and RMSE. A low p-value like 0.02 (<0.05) suggests that the observed data's fit to the expected data. Both the low RMSE and the small MAPE values suggest that your predictive model is performing well in predicting time headway values for the validation data. By offering a quantitative tool for forecasting time headways, the research opens avenues for enhancing traffic management strategies and optimizing bus stop layouts.

Speed-flow diagrams reveal a significant capacity reduction at curbside bus stop sections, underscoring their impact on traffic flow efficiency. By calculating critical time headways based on these capacities, a reliable benchmark for assessing traffic performance and congestion is established, aiding roadway design decisions. Notably, on six-lane divided roads, despite an outer lane dedicated to bus stops, higher capacity allows for shorter time headways and more efficient traffic flow compared to four-lane divided roads. Consequently, critical time headway is lower in six-lane sections. This comprehensive study provides fresh insights into transportation engineering, paving the way for more effective traffic management and urban planning solutions.

7. Conclusions

This study analyzed time headway in vehicular streams on four-lane and six-lane urban roads with curbside bus stops, involving probability distribution analysis across different lanes and traffic levels. It developed a mathematical expression using MLR to estimate average time headway based on traffic and roadway parameters. Speed and volume diagrams determined section capacity with and without bus stops. The study also calculated critical time headway at traffic volume capacity levels and defined threshold values before bus stop congestion. Key findings are summarized below.

1. Statistical distribution analysis of time headway reveals right-skewed distribution curves, indicating poor operational traffic conditions at bus stop locations
2. Lane position significantly affects time headway. The shape parameter is higher in the inner, middle, and outer lanes at mid-block sections compared to bus stop sections, indicating that the bus's presence affects the distribution pattern when the outer lane is blocked.
3. The time headway data distribution observed on divided urban roads showed different behavior at different traffic volume levels. With moderate traffic volume (500 – 1,500 PCU/hr) fitted to Generalized Gamma distribution and, with moderate to high traffic volume (1,500 – 3,500 PCU/hr) fitted best to Generalized Extreme Value (GEV) distribution, and with higher traffic flow (>3,500 PCU/hr) fitted best to Wakeby distribution.
3. Descriptive analysis examines time headway between different vehicle pairs, revealing that vehicles with poorer operating characteristics or larger dimensions tend to maintain larger gaps between leading and following vehicles, leading to increased headway values.
4. Factors affecting time headway include traffic volume, percentages of two-wheelers and heavy vehicles, bus dwell time, and lane count. A multiple-factor regression analysis developed models to predict mean time headway at bus stops and mid-blocks on multilane divided roads. Model validation achieved a 2.30% MAPE using data from additional locations.
5. Critical time headway is calculated for each location using section capacity as an input variable, derived from speed-flow curves. It represents a threshold value before congestion occurs. Comparative analysis reveals accurate critical time headway estimates from the proposed model, with a 6.49% MAPE value.
6. The time headways are observed to increase at all bus stop sections in a range of 6.25% to 9.8% compared to mid-block sections which lead to a reduction in speed (ranging 15.93% to 22.57%) and capacity (ranging 4.33% to 7.27%).

This study makes several novel contributions, enhancing our understanding of traffic dynamics at curbside bus stops. It stands out by comprehensively analyzing time headway distributions in various lanes and traffic conditions, focusing specifically on bus stop locations. Additionally, it introduces a novel predictive multiple linear regression model for estimating time headways at bus stops, advancing traffic management. The investigation into critical time headways further underscores the research's uniqueness. In essence, this research distinguishes itself by exploring traffic behavior, developing a predictive model, and establishing performance metrics for curbside bus stop sections.

The study's findings aid bus stop layout planning and enhance traffic flow facility capacity and performance. These insights are valuable for urban planning, transportation engineering, and traffic management. However, the study focuses solely on urban mid-block roads with bus stop side friction. Future research may investigate mixed side frictions like on-street parking, pedestrian movement, non-motorized vehicles, and wrong side movement. Subsequent studies could integrate real-time data and advanced modeling for dynamic traffic management near bus stops.

Acknowledgments

Not Applicable

ORCID

Sruthi Sekhar Pallela https://orcid.org/0000-0002-1088-4108
Arpan Mehar https://orcid.org/0000-0002-1680-2089

References

Abtahi SM, Tamannaei M, Haghshenash H (2011) Analysis and modelling time headway distributions under heavy traffic flow conditions in the urban highways: Case of isfahan. *Transport* 26(4): 375-382, DOI: 10.3846/16484142.2011.635694

Adams W (1936) Road traffic considered as a random series. *Journal of the Institution of Civil Engineers* 4:121-130

Al-Ghamdi A (1999) Entering headway for through movements at urban signalized intersections. *Journal of Transportation Research Board, Trasnportation Research Record* 1678(1):42-47, DOI: 10.3141/1678-06

Al-Ghamdi AS (2001) Analysis of time headways on urban roads: Case study from Riyadh. *Journal of Transportation Engineering-ASCE* 1274(4):289-294, DOI: 10.1061/(ASCE)0733-947X(2001)127:4(289)

Alhamdany M, Albayati AH (2022) Statistical modeling of time headway on urban roads: A case study in baghdad. *Engineering, Technology & Applied Science Research* 12(3):8584-8591, DOI: 10.48084/etasr.4878

Arasan VT, Koshy RZ (2003) Headway distribution of heterogeneous traffic on urban arterials. *Journal of the Institution of Engineers* 84: 210-215, http://cat.inist.fr/?aModele=afficheN&cpsidt=15411224

Aydin D (2007) Predicting the effect of zmir ring road on traffic flow at Alt nyol. MSc Thesis, Dokuz Eylül University Graduate School of Natural and Applied Sciences, Zmir

Das S, Maurya AK (2017) Time headway analysis for four-lane and two-lane roads. *Transportation in Developing Economies* 3(9): DOI: 10.1007/s40890-017-0039-8

Das S, Maurya AK (2018) Multivariate analysis of microscopic traffic variables using copulas in staggered car-following conditions. *Transpometrica A: Transport Science*, 1-26, DOI: 10.1080/23249935.2018.1441200

Das S, Mahapatra G, Maurya AK, Minhans A (2015) An empirical study of vehicle time headways for different roadway facilities. *3rd Conference of Transportation Research Group of India (3rd CTRG)*

Dubey S, Ponnu B, Arkatkar SS (2013) Time gap modeling using mixture distributions under mixed traffic conditions. *Journal of Transportation Systems Engineering and Information Technology,* 13(3):91-98, DOI: 10.1016/S1570-6672(13)60110-5

Dubey SK, Ponnu B, Arkatkar SS (2012) Time gap modelling under mixed traffic condition: A statistical analysis. *Journal of Transportation Systems Engineering and Information Technology* 12(6):72-84, DOI: 10.1016/S1570-6672(11)60233-X

Greenberg I (1966) The log-normal distribution of headways. *Australian Road Research* 2(7):14-18

Haryadi B, Narendra A (2016) Vehicle headyway distribution models on two-lane two-way undivided roads. *International Journal of Innovative Research in Advanced Engineering* 3(7):57-63

Hossain DM, Iqbal GA (1999) Vehicular headway distribution and free speed characteristics on two-lane two-way highways of Bangladesh. *Journal of the Institution of Engineers* 80:77-80

Indo-HCM (2017) Indian highway capacity manual. New Delhi: (MoRTH), Ministtry of Road Transport and Highways, Centre for Scientific and Industrial Research

Issac KP, Veeraragavan A (1995) Headway distribution as input to simulation models under mixed traffic flow. Proceedings of the National Seminar on Emerging Trends in Highway Engineering. Banglore

Jang J, Park C, Kim B, Choi N (2011) Modeling of time headway distribution on suburban arterial: Case study from South Korea. *Procedia - Social and Behavioral Sciences* 16:240-247, DOI: 10.1016/j.sbspro.2011.04.446

Katti BK, Phatak RH (1985) A study on headway distribution models for the urban road sections under mixed traffic conditions. *Highway Research Bulletin* 26:1-31

Kinzer JP (1934) Applications of the theory of probability to problems of highway traffic. Proceedings of Institution of Traffic Engineers, 118-123, DOI: 10.2307/2983631

Kota R, Mehar A (2022) Occupancy time characteristics of right-turning traffic on minor approach at urban uncontrolled intersection. *Advances in Transportation Studies, LVIII*, 277-294, DOI: 10.53136/979122180230618

Kumar R, Chandra S (2001) Headway modelling under mixed traffic on urban roads. *Road and Transport Research* 10(1):61-71

Kumar VM, Rao SK (1998) Headway and speed studies on two lane highways. *Indian Highways* 26(5):23-36

Li Y, Sun D, Liu W, Zhang M, Zhao M, Liao X, Tang L (2011) Modeling and simulation for microscopic traffic flow based on multiple headway, velocity and acceleration difference. *Nonlinear Dynamics*, DOI: 10.1007/s11071-010-9907-z

Maurya AK, Das S, Dey S, Nama S (2016) Study on speed and time-headway distributions on two-lane bidirectional road in heterogeneous traffic condistion. *Transportation Research Procedia* 17:428-437, DOI: 10.1016/j.trpro.2016.11.084

May AD (1990) Traffc flow fundamental. Prentice-Hall: Englewood Cliffs

Moridpour S, Aliakbari M (2016) Headway distributions in urban highways under heavy traffic conditions. *Journal of Geotechnical and Transportation Engineering* 2(2):39-45

Mukherjee SK, Rao SK, Chowdhury ML (1988) Fitting a statistical distribution for headways of approach roads at two street intersections in Calcutta. *Journal of the Institution of Engineers* 69:43-48

Pallela SS, Mehar A (2022) Examining the effect of curb-side bus stop on time headway at multilane divided urban roads under mixed traffic conditions. *Transportation in Developing Economies* 8(27), DOI: 10.1007/s40890-022-00162-7

Pallela SS, Mehar A (2023) Examining the lane-wise time headway and speed characteristics at curb-side bus stop on four-lane divided urban arterials. *Journal of Institute of Engineers India, Series A* 104: 367-380, DOI: 10.1007/s40030-023-00720-1

Sahoo PK, Rao SK, Kumar VM (1996) A study of traffic flow characteristics on two stretches of national highway No. 5. *Indian Highways* 24(4):11-17

Shoaeb A, El-Badawy S, Shawly S, Shahdah UE (2021) Time headway distributions for two-lane two-way roads: Case study from Dakahliya governorate, Egypt. *Innovative Infrastructure Solutions* 6(3):141-152, DOI: 10.1007/s41062-021-00531-y

Sooksan P (2014) Time-headway distributions on an expressway: Case of bangkok. *Journal of Transportation Engineering* 141(1), DOI: 10.1061/(ASCE)TE.1943-5436.0000731

Suresh V, Umadevi G (2014) Empirical methods of capacity estimation of urban roads. *Global Journal of Researchers in Engineering: J General Engineering* 14(3):9-24

Traffic Engineering Handbook (1965) Baerwald, J.E. and Institute of Traffic Engineers. Institute of Traffic Engineers, 65017560, https://redlightrobber.com/red/links_pdf/Traffic-Engineering-Handbook-1965-3rd-Edition.pdf

Yigiter OC, Tanyel S (2015) Lane by lane analysis of vehicle time headways-Case study of Izmir ring roads in Turkey. *KSCE Journal of Civil Engineering* 19(5):1498-1508, DOI: 10.1007/s12205-014-0267-y

Yu R, Zhang Y, Wang L, Du X (2022) Time headway distribution analysis of naturalistic road users based on aerial datasets. *Journal of Intelligent and Connected Vehicles* 5(3):149-156, DOI: 10.1108/JICV-01-2022-0004

Zhang M, Meng Q, Kang L, Li W (2018) Tailored wakeby-type distribution for random bus headway adherence ratio. *Transportation Research Part C: Emerging Technologies* 86:220-244, DOI: 10.1016/j.trc.2017.11.013

Zwahlen HT, Oner E, Suravaram K (2007) Approximated headway distributions of free-flowing traffic on Ohio freeways for work zone traffic simulations. *Transportation Research Record* 1999:131-140, DOI: 10.3141/1999-14