Transportation Research Interdisciplinary Perspectives 9 (2021) 100298

Contents lists available at ScienceDirect

Transportation Research Interdisciplinary Perspectives

journal homepage: www.elsevier.com/locate/trip

Impact of vehicular traffic stream on pedestrian crossing behavior at an uncontrolled mid-block section

Somya Agarwal, Durgesh Vikram *

Department of Civil Engineering, Birla Institute of Technology and Science Pilani, Pilani Campus, Rajasthan 333031, India

ARTICLE INFO

Keywords:
Uncontrolled mid-block section
Interaction between pedestrian and vehicular traffic
Pedestrian road crossing time
Pedestrian waiting time

ABSTRACT

A term Total Crossing Time (TCT) is coined in this study. TCT of a pedestrian includes the time spent by the pedestrian in waiting and his/her crossing of a road. This paper argues that considering a distribution of TCT is required for analysis instead of analyzing a crisp value of TCT of pedestrians. This study quantifies, perhaps for the first time, that by what extent vehicular traffic streams affect TCT distribution of pedestrians crossing an uncontrolled mid-block section of an urban road. For this, a suitable parameter of traffic stream that influences TCT distribution is identified. The suitable parameter of traffic is found to be the traffic density. Further, it is hypothesized that pedestrians can only perceive a range of traffic density and not discrete values of density. In order to incorporate this, traffic density observed on the road is categorized into nine groups; and, for each group of densities corresponding TCT distribution is computed. Curve fitting, using two kinds of density functions, for each of the nine TCT distributions is performed and Pearson Type-III density function is found to be a more appropriate distribution. Additionally, the parameters of the fitted Pearson Type-III distribution are found to be dependent on the corresponding mean of the traffic density group. Hence, a simple regression model is also suggested using which one can predict TCT distribution if traffic density of the stream is known. The findings of this study is going to be useful for researchers/practitioner those who are interested in simulating pedestrians, crossing an uncontrolled mid-block section of a road.

Introduction

The rise in urban population has resulted in an increase in vehicular and pedestrian traffic in urban areas (see Pucher et al., 2007). Pedestrians, particularly those who wish to cross a road, are more vulnerable to accidents than pedestrian's maneuvering at sidewalks. Crossing of a road by pedestrians can take place either through a nearby intersection or at the mid-block. Road crossing at mid-blocks takes place due to pedestrian's urge to reach the nearby facility at the earliest. It is observed that there exist significantly higher amount of conflicts if pedestrians cross at a mid-block section rather than crossing at an intersection (see Cui and Nambisan, 2003). The reason for a higher number of conflicts between vehicles and pedestrians is due to the fact that during pedestrian crossing at mid-blocks space sharing takes place by both vehicular and pedestrian traffic. This kind of space sharing leads to ambiguity in yielding behavior of both vehicles and pedestrians. Further, it is pedestrians who are highly susceptible to severe road injuries than vehicles in case of an accident. Unfortunately, pedestrians tend to cross a road at mid-blocks, of course illegally, overlooking the high accident risk (see Havard and Willis, 2012; Shaaban et al., 2018; Sisiopiku and Akin, 2003; and, Zheng et al., 2015). Therefore, necessity of studies related to pedestrian crossing at mid-blocks cannot be overstated.

In order to design facilities that can reduce accidents due to vehicle and pedestrian conflict at mid-block sections, researchers are required to analyze such events. But, only a few studies related to such pedestrian crossings is available in literature. Further, the existing literature in this area can be broadly classified into two categories. These are (i) studies related to safety issues of pedestrians, and (ii) studies concerned with impact of pedestrian and vehicular traffic characteristics on road crossing behavior of pedestrians. Studies that are concerned with pedestrian safety, considering pedestrians crossing a road at mid-blocks, utilize a term called Pedestrian Safety Margin (PSM) (see Chaudhari et al., 2019; and, Vedagiri and Kadali, 2016). PSM is defined as the time difference between the time gap of an approaching vehicle and the pedestrian crossing time. By making use of PSM some studies predicted pedestrian-vehicle accident severity, while others have come up with methodology, using ANN and multiple linear regression, to predict the PSM values. While predicting these values, studies treated pedestrian characteristics, like age, gender, pedestrian speed, etc., and vehicular traffic characteristics, like speed and type of on-coming vehicles, etc., as inputs.

* Corresponding author.
E-mail address: durgesh.vikram@pilani.bits-pilani.ac.in (D. Vikram).

https://doi.org/10.1016/j.trip.2021.100298
Available online 22 January 20212590-1982/© 2021 Published by Elsevier Ltd.

The second category of studies, available in literature, discuss gap acceptance behaviour of pedestrians, waiting time distribution of pedestrians, crossing time distribution of pedestrians, and identification of dilemma zone on the road for pedestrians (see Kadali et al., 2015; Pawar et al., 2016; and, Shaaban et al., 2018). Present study also belongs to this category and it focuses on road crossing time distribution of pedestrians. At first, an argument is presented in favour of analyzing road crossing behaviour of pedestrians using crossing time distribution over a crisp value of crossing time. The road crossing behaviour of pedestrians is an outcome of the interaction between their urgency to reach the other side of a road and their safety while performing this task. Of course, different pedestrians have different level of urgency and risk taking capability. For an example, elderly pedestrians particularly those with issues related to walking would be more cautious while crossing a road, whereas younger pedestrians would be more prone to taking risk. This will result in different values of road crossing times for different pedestrians. Therefore, road crossing times of pedestrians can be stated to be stochastic in nature.

In regions where vehicular traffic consists of variety of vehicles and traffic does not follow lane discipline, the pedestrians are involved in rolling gap acceptance. For example, consider a four lane divided road. Of course, two lanes are dedicated to vehicular traffic in each direction. Under rolling gap acceptance, a pedestrian first crosses only a part of the entire road width by accepting a gap and then he/she waits there for another acceptable gap for crossing another part of the road; and, this continues till the pedestrian completes the crossing maneuver. Further, following similar behaviour he/she crosses the other half of the road as well. For further understanding of the concept of rolling gap acceptance behavior of pedestrians one may refer to Zhuang and Wu (2011).

Interestingly from our video data, it was observed that many a times pedestrians did not come to a complete halt, while crossing the road, when they were in the middle of the road rather they reduced their crossing speed significantly due to vehicular movement. Because of such behavior of pedestrians, waiting time cannot be described clearly. For this reason, in this study a term Total Crossing Time (TCT) of pedestrians is coined, which is simply the amount of time spent by a pedestrian interacting with vehicular traffic stream while crossing the road. It can be observed that total waiting time of a pedestrian gets included in his/her TCT. This paper focuses on studying impact of traffic characteristics on the distribution of TCT. This study has two objectives: (i) to find the suitable traffic flow parameter that affects TCT distribution, and (ii) to model the variation in TCT distribution with the variation in the selected parameter of vehicular traffic.

It is further hypothesized in this study that road crossing time distribution of pedestrians gets affected also by vehicular traffic characteristics. The motivation for such a hypothesis is discussed now. As an example, if consecutive vehicles in a traffic stream are separated by a larger distance on a section of a road then it can be safely stated that waiting time of pedestrians would be insignificant and thereby TCT of pedestrians would be on a lesser side. On the other hand, if vehicles of a stream, at the same section, are closely spaced then it can be stated that waiting time of pedestrians would be significant leading to higher TCT of pedestrians. Therefore, it can be stated that TCT distributions of pedestrians also depend on vehicular traffic characteristics. But, none of the studies has incorporated impact of vehicular traffic characteristics on road crossing time distribution of pedestrians.

The paper consists of six sections, out of which this is the first. The second section is about the site and data description. This section elaborates on the study area and the way raw data are processed for the study purpose. The third section is about the selection of a suitable vehicular traffic parameter that impacts TCT distribution. The fourth section presents data analysis that includes developing models of TCT distribution using the empirical observations. The fifth section discusses the development of models for predicting the values of parameters that are involved in TCT distribution using the vehicular traffic characteristic. The last section summarizes the entire work of the paper.

Site and data description

The site details and road crossing data of pedestrians along with relevant vehicular traffic parameter are discussed and presented in this section.

Site details

The data was collected from Johari Bazar area, Jaipur city, India and the sattelite image of the location is shown in Fig. 1. The selected site is a midblock section, which is a four lane divided urban road. The width of the road in each direction of traffic movement is 7 m. The median width is 1 m. The section of the road lies in a commercial area. Pedestrians have direct access to the section of the road under observation. Pedestrian crossing against only one direction of movement of vehicles is considered at the mid-block and a schematic of that part of the road segment is presented in Fig. 2. Vehicular movement for this half of the road takes place from the right to the left. The vehicular flow varies from 600 to 2400 in terms of passenger car units per hour (PCU/h). Further, the cross-section A-A in Fig. 2 represents the direct access to the road for the pedestrians. The width of the access, i.e., section A-A, is 3 m. The average flow of pedestrians crossing the mid-block section is 510 pedestrians/hour. The total number of pedestrians used as samples in this study is 2040.

In order to collect the data, videography survey was carried out during daytime on a working day. The camera was installed adjacent to the road such that a complete view of the part of the mid-block section is available. This implies that all the road users (vehicles and pedestrian) at that section of the road are observable. The data from video recording was extracted manually using AVI video editor. The data regarding pedestrian arrival/exit and simultaneously arrival/departure of vehicles is extracted. The least count of pedestrian arrival/exit time and vehicle arrival/departure time is used as 0.04 s. Pedestrians arrive in the study zone from both the median and the opening as shown in Fig. 2. For the pedestrians approaching from the opening side, the time at which any pedestrian arrives at the section A-A is assumed to be the arrival time. Similarly, the time of arrival of a pedestrian at the median is assumed to be his/her arrival time. The exit time of a pedestrian is assumed to be the time when the pedestrian reaches the opposite end i.e. the median or the observable road edge. The Total Crossing Time (TCT) is defined as the total time taken by the pedestrian to move from section A-A to median or vice versa. In other words, TCT is expressed as the difference in exit time and arrival time. In general, the crossing time values are found to be in the range of 4s to 30s.

Data proccessing

The vehicular traffic data such as speed, density, and flow are also extracted from the video data. Traffic stream characteristics such as flow rate of the vehicles is defined as the number of vehicles crossing the section B-B per unit time. It was observed from the video data that there exist seven classes of vehicles in the traffic stream. The existence of different classes of vehicles in traffic streams at the site creates difficulty in reporting flow value in one uniform unit, i.e., number of vehicles per unit time. To find the flow values for such a heterogeneous traffic stream in one uniform unit, the number of vehicles of each category is multiplied by its corresponding Passenger Car Unit (PCU) using the method suggested by Chandra et al. (2017). The extracted data consist of 2 h of morning period (10:30 A.M.-12:30 P.

Fig. 1. Sattelite image of the mid-block section studied.

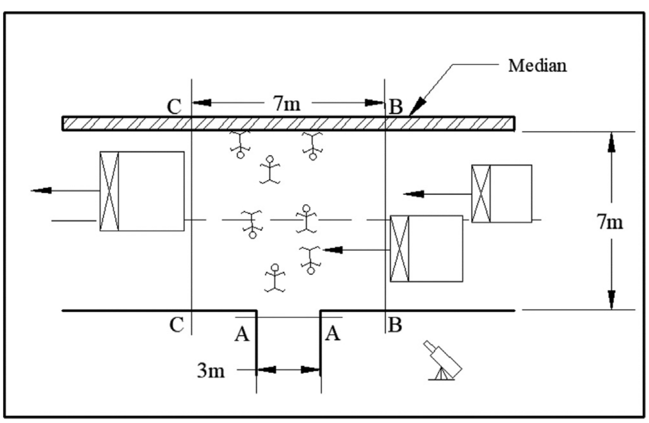

Fig. 2. Schematic of the mid-block section studied.

M.) and 2 h of evening period (2:00 P.M.-4:00 P.M.). The following represents the total vehicular flow rate (Q) in equivalent number of cars:

$$Q = \sum_{\forall i} PCU_i \times q_i \tag{1}$$

where, PCU_i and q_i are the passenger car equivalent and vehicular flow rate of i^{th} class of vehicles, respectively. Now, to calculate the speed of vehicles, two sections, namely B–B and C–C, were marked on the computer screen. These sections are shown in Fig. 2. The distance between these two sections is 7 m. The time taken by a vehicle to reach section C–C from section B-B is noted for each vehicle to find out the speed of the vehicle. The speed of each vehicle thus obtained can be treated as spot speed of the vehicle. Thus, the space mean speed of a traffic stream is expressed as:

$$U = \frac{\sum_i q_i \times PCU_i}{\sum_i \frac{q_i \times PCU_i}{u_i}} \tag{2}$$

Another traffic flow parameter, i.e., traffic density, is calculated by using the fundamental equation of traffic flow (i.e., $Q = U \times k$). It can be observed that if traffic stream parameters (Q and U) are known, one can compute traffic density of the stream.

Traffic flow parameter affecting pedestrian crossing behavior

Using the macroscopic traffic flow parameters like flow, density, and speed, one can uniquely represent a traffic stream. But, it is not clear that which one of the three parameters should be utilized to account for the impact of a traffic stream on TCT distribution. At first, an argument is presented to show that traffic speed cannot be that parameter of a traffic stream. According to Highway Capacity Manual (2010), over a long range of traffic flow rate, stream speed remains invariably the same. This is true particularly when a traffic stream operates under free-flow condition. This property indicates that one cannot depend on traffic speed to uniquely define a traffic stream; and, the impact of traffic stream on TCT distribution cannot be modeled using stream speed. This leaves us with two parameters, traffic flow rate, and traffic density, to choose as a possible candidate that can capture impact of traffic streams on TCT distribution.

Two different vehicular traffic streams are considered. Both streams have the same flow rate (approximately) but different densities. Further, one traffic condition represents free flow traffic and the other represents forced flow condition of traffic. These two traffic conditions are utilized here to single out a suitable parameter. The range of traffic flow rate of these two streams is 600–900 PCU/h; and TCT distributions of pedestrians are compared for this range of traffic flow rate. TCT distribution of pedestrians facing the two streams while crossing the road are presented in Fig. 3. Fig. 3(a) represents the TCT distribution in presence of free-flow traffic conditions, whereas Fig. 3(b) represents the TCT distribution in presence of congested traffic conditions. The minimum and maximum TCT was observed to be 4 s and 26 s. This can be seen in the relative frequency plots where one can observe zero pedestrian counts before 4 s and beyond 26 s. A class

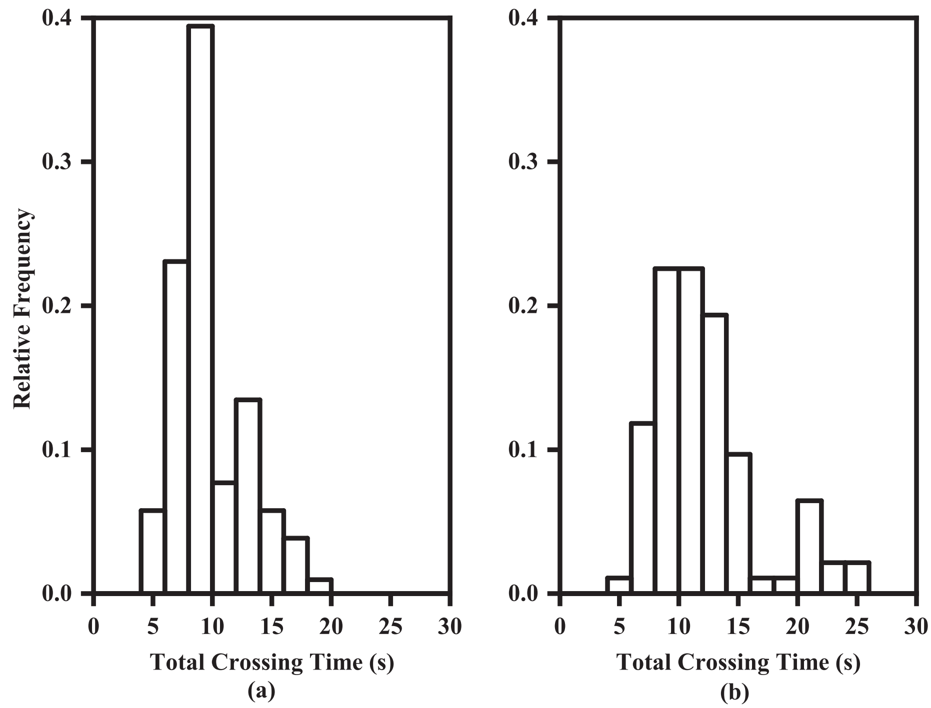

Fig. 3. Histograms of TCT distribution against traffic with similar flow rate but representing (a) free flow traffic, and (b) congested traffic conditions.

interval of 2 s is utilized here, and therefore a total of 11 classes are identified. The number of pedestrians against the congested traffic condition is 110, and against the free flow traffic condition is 104.

Hypothesis testing using a chi-square test was carried out to compare the two distributions. The null hypothesis (H_0) is that both the distributions belong to the same population, i.e., pedestrian total crossing time distribution is same while facing the two traffic streams. The alternate hypothesis (H_1) states that both TCT distributions belong to different populations, i.e., TCT distributions are different while facing the two traffic streams. Chi-square test for comparing two data sets with an unequal number of data points is presented in Press et al. (1992) and the same is utilized here.

The calculated value of Chi-square is found to be 41.726. The degrees of freedom are 11, and considering the 0.05 significance level, Chi-square value is 21.9 from the standard table. Since the calculated Chi-square value is greater than the Chi-square value from the table, it can be stated that there is statistical evidence to reject the null hypothesis. Therefore, the concluding statement based on a statistical test is that it is unlikely that the two distributions belong to the same population. This demonstrates that the TCT distributions for the same flow rate with different traffic densities are different. Therefore, traffic density is a better parameter in comparison to the traffic flow rate to model the impact of traffic flow parameters on TCT distribution.

Analysis of data

Pedestrian crossing time (here, TCT) is stochastic in nature. The motivation for such a behaviour of pedestrians is presented in the Introduction section of this paper. It can be further stated that at a given traffic density, the road crossing time of different pedestrians could be different for the same section of a road. It necessitates one not to come up with a single value of TCT but a distribution of TCT. However, TCT is a perception-reaction process between pedestrians trying to cross a road in presence of various traffic density. It is hypothesized here that the pedestrians do not perceive the small changes in traffic density easily. Therefore, it is required to group traffic densities. From the macroscopic point of view, the study of TCT for a different range of density is meaningful instead of studying pedestrian crossing time at single-density values. It is assumed here that, for a range of traffic density, the behavior of pedestrians remains more or less similar.

Considering the above-mentioned statements, the vehicular density is grouped into nine groups with each group having a range of 20 PCU/km, such as 10–30 PCU/km, 30–50 PCU/km, and so on till 170–190 PCU/km. The TCT corresponding to each group of vehicular density is analyzed by computing relative frequency of different TCT classes. The class interval of total crossing time is adopted as 1 s ranging from 4 s to 25 s for each group of density. This way histograms are prepared for each range of density and are presented in Fig. 4.

Nature of the observed and candidate TCT distributions

It can be observed from Fig. 4. that the size of the peaks in the TCT distribution are reducing as the density is increasing. Not only the size of the peak is reducing but it is also shifting towards higher TCT values with an increase in traffic density. This can be found by comparing Fig. 4(a) with Fig. 4(b). These two histograms also imply that TCT distributions get flatter as vehicular density increases. This means that the TCT distribution at low traffic density has a significant relative frequency in a narrower region (observable in Fig. 4(a)) as compared to TCT distributions at higher traffic density (observable in Fig. 4 (i)). This indicates that a crisp value of TCT is a tenable idea if traffic density is low, but the same cannot be said for TCT at high traffic densities. At low traffic density, like 10–30 PCU/km (as shown in Fig. 4 (a)), the TCT is concentrated between 6 and 10 s. This indicates that the more number of pedestrians are taking 6–10 s to cross the road section. However, at a high traffic density of 170–190 PCU/km, the crossing times of pedestrians are spread over a larger range of TCT values, i.e., 6 s to 21 s.

To model such a distribution of data, one needs a probability density function that reflects the property where the peak shifts and also gets flatter. The two probability density functions, namely Pearson Type-III and Three-Parameter Weibull, are found suitable to fit the data. Let t be the non-negative variable representing the TCT in sec-

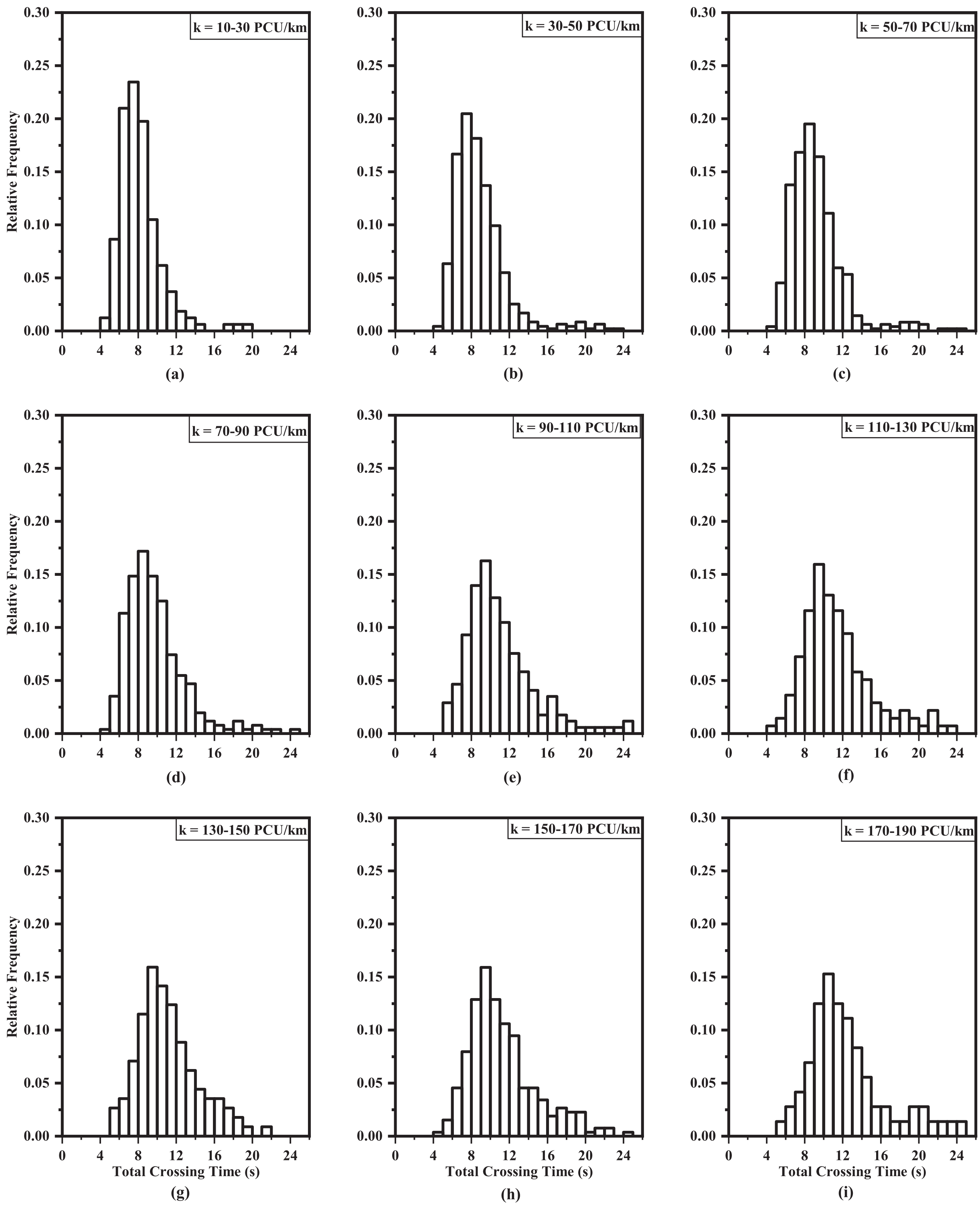

Fig. 4. Histograms of TCT distribution against nine different traffic densities varying from (a) free flow traffic to (i) congested traffic conditions.

onds, and $f(t)$ denotes the probability density at t. Mathematically, functional form of the probability density function of Pearson Type-III is given by:

$$f(t;\alpha,\lambda,K) = \frac{\lambda}{\Gamma(K)}\{\lambda(t-\alpha)\}^{(K-1)}\exp^{-\lambda(t-\alpha)} \tag{3}$$

The variation in the shape of Pearson's Type III distribution with all the three parameters is presented in Fig. 5. The parameter α of the distribution is a shift parameter, which causes shift of the beginning of curve along with the peak. However, the size of the peak remains unaltered with the variation in α value. The curve along with its peak shifts towards higher TCT with increase in the value of α (see Fig. 5(a)). The parameter λ controls spread of the distribution over TCT. It can be observed from Fig. 5(b) that spread of the curve gets narrower and the curve shifts towards left with increase in the value of λ. Further, since spread of the curve decreases with increase in λ, therefore peak size increases with increase in λ. The parameter K controls the shift, sharpness, and the size of the peak of the curve. With increase in the

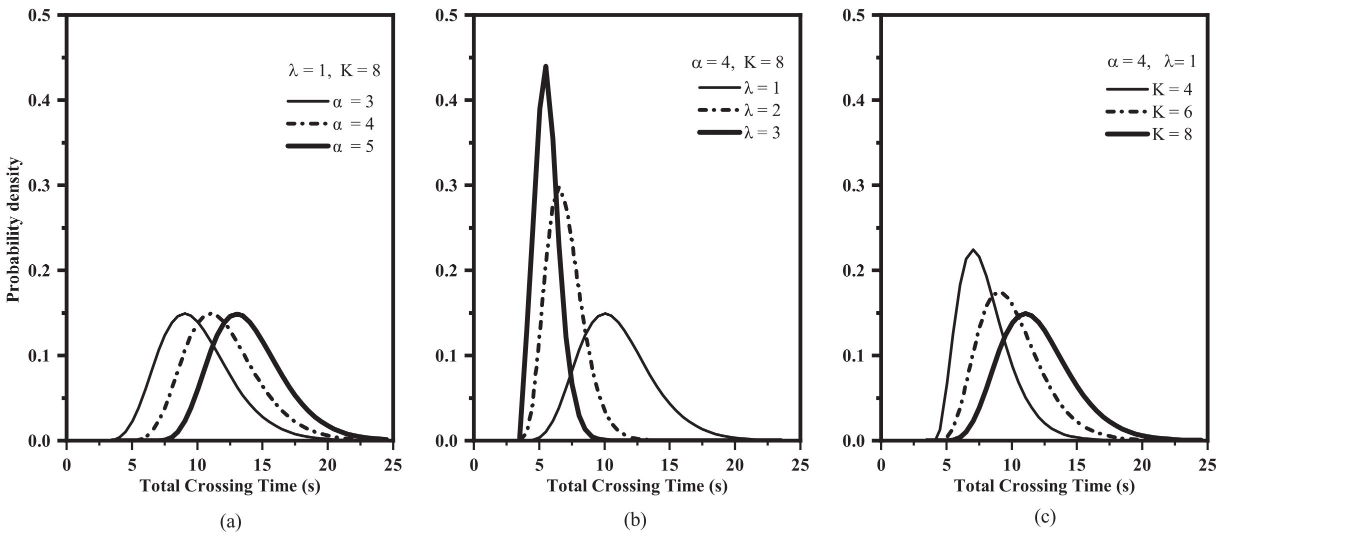

Fig. 5. Variation of Pearson Type-III distribution with parameters (a) α, (b) λ, and (c) K.

value of this parameter, the curve becomes flatter and shifts towards right side and size of the peak reduces (see Fig. 5(c)). Now, the probability density function of Three-Parameter Weibull distribution is as follows:

$$f(t;\beta,\eta,\gamma)=\frac{\beta}{\eta}\left(\frac{t-\gamma}{\eta}\right)^{(\beta-1)}\exp^{-\left(\frac{t-\gamma}{\eta}\right)^{\beta}} \tag{4}$$

The variations in the shape of three parameter Weibull distribution with the variation in all three parameters are presented in Fig. 6. The parameter γ controls the shift of the curve keeping the size of the peak intact. The parameter β controls spread of the distribution over TCT. With the increase in value of β, the size of the peak increases, and the spread of the curve reduces (see Fig. 6(b)). The parameter η controls the shift, sharpness, and the size of the peak of the curve (see Fig. 6(c)). With an increase in the value of this parameter, size of the peak of the curve decreases and the distribution moves towards right. Next, a brief discussion is provided about fitting the observed frequency to the two probability density functions.

A suitable theoretical TCT distribution

Let F^i_{th} be the theoretical probability that crossing time lies between the time interval t_i and $t_i+\Delta t$. Then,

$$F^i_{th}=\int_{t_i}^{t_i+\Delta t} f(t)dt \tag{5}$$

Let F^i_o be the observed relative frequency for the i^{th} class of TCT value. Then the difference between observed and theoretical probabilities of the i^{th} class of TCT value is defined as error in predicting the probability of i^{th} class of TCT values and the error is represented as follows:

$$e_i=F^i_o\Delta t-F^i_{th} \tag{6}$$

With this description of error, Least Square estimation (LSE) of the parameters is a process that determines the parameters of a density function that minimizes the sum of squared errors. The parameters

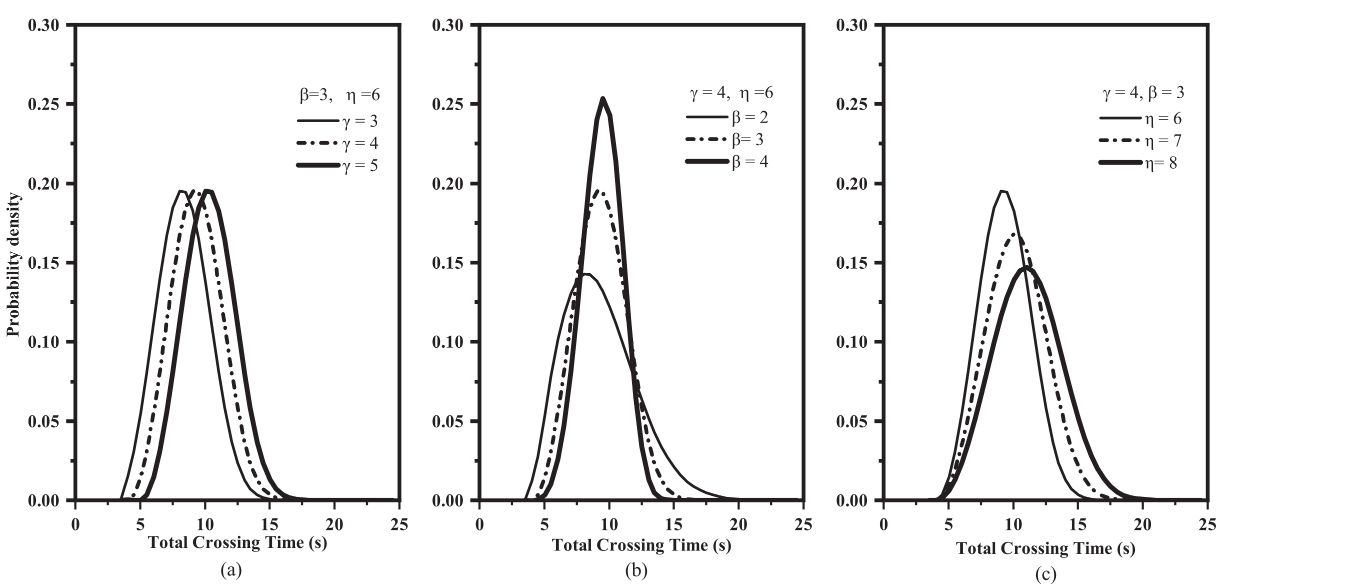

Fig. 6. Variation of three parameter Weibull distribution with parameters (a) γ, (b) β, and (c) η.

Table 1
The obtained RMSE values of the estimated Pearson Type-III and three parameter Weibull distributions against nine different range of vehicular traffic densities.

Vehicular density range in PCU/km	RMSE	
	Pearson Type-III	Three-Parameter Weibull
10–30	0.014	0.021
30–50	0.013	0.020
50–70	0.011	0.020
70–90	0.012	0.021
90–110	0.016	0.019
110–130	0.015	0.018
130–150	0.015	0.015
150–170	0.013	0.014
170–190	0.016	0.018

of the Pearson Type-III distribution, i.e. (α, λ, and K) and those of Weibull distribution, i.e. (β, η, and γ) are estimated using LSE. The parameters thus estimated using LSE leads to solving an unconstrained multivariate non-linear optimization problem. In the present case, the procedure is an iterative process because the closed-form solutions are not available. A conventional optimization technique, (here, Modified Newton's method of optimization) is applied to estimate the parameters. For a detailed discussion on Modified Newton's method, one can refer to Dasgupta (2006).

By making use of the above mentioned strategy, each histogram of TCT is fitted with the two probability density functions. This implies two different curves are fitted for each histogram. However, ultimately one needs only one curve to represent a histogram. Therefore, the best fitted curve for each histogram needs to be identified. In this study, Root Mean Square Error (RMSE) is utilized as the performance indicator to select the best out of the two PDFs. RMSE of each TCT distribution for the two selected PDFs is presented in Table 1. It is well known that lower the RMSE value better the fit of the theoretical distribution with the observed data. From Table 1, it can be inferred that TCT distribution corresponding to each class of vehicular density Pearson Type-III distribution is better. Therefore, only Pearson Type-III distribution is utilized in this study to analyze further the TCT distribution for different groups of traffic density.

Goodness of fit test of the distribution

The better model, among the two considered PDFs, is selected using RMSE. However, it is also essential to show statistically that how close the estimated distribution, using Pearson Type-III distribution, is to the empirical data. For this, hypothesis testing is carried out to statistically compare the closeness of each fitted curve (theoretical distribution) to corresponding histograms of TCT (empirical distribution). Comparison is made between a histogram and the corresponding Pearson Type-III distribution using Chi-square test. Here, the null hypothesis (H_0) is that the fitted curve represents the corresponding histogram and there is only insignificant difference between the measured TCT distribution and the theoretical distribution at 0.05 significance level. The alternate hypothesis (H_1) is that the two distributions are different.

There are nine different histograms for nine different groups of vehicular traffic density. The Chi-square test is performed for each histogram of TCT and the corresponding curve. The degree of freedom is found to be 8 as there are 12 class intervals of TCT and 3 unknown parameters of Pearson Type III distribution for each histogram. The Chi-square test results are presented in Table 2. At a significance level of 0.05, the chi-square value from the standard table comes out to be 15.5. This value is higher than the Chi-square value calculated for each of the nine different TCT distributions. Therefore, it can be stated that statistically there is no evidence to reject the null hypothesis for any of the nine curves that are fitted.

The fitted Pearson Type-III distributions are presented in Fig. 7 along with their corresponding histograms of TCT. It can be observed from Fig. 7 that there is a gradual shift in the peak of distribution model from smaller crossing time (6–10 s) to larger crossing time (8–14 s.) with an increase in vehicular density. Also, with an increase in vehicular density the plot gets flatter; and, this indicates higher chances of increase in total crossing time due to increase in pedestrian-vehicle interaction. At lower vehicular density, a sharp peak can be observed between 6 and 10 s of crossing time owning to lesser level of pedestrian-vehicular interaction while crossing the road section by pedestrians. Similarly, with an increase in the vehicular density, the amount of pedestrian-vehicular interactions also increases, thereby, increasing the pedestrian crossing time. Therefore, it can be said that pedestrian-vehicular interaction has an impact on pedestrian crossing time. For clarity, the fitted Pearson's Type III distribution of PCT for the densities 10–30 PCU/km, 90–110 PCU/km and 170–190 PCU/km are presented in Fig. 8 and it supports the above mentioned statements.

Empirical model

$$\alpha = 4$$
$$\lambda = 1.858 - 0.009 \times k + 0.00003 \times k^2$$
$$K = 7.323 + 0.00004 \times k + 0.00004 \times k^2$$

Pearson Type-III distribution involves three parameters (α, λ, and K) and it is observed while fitting the curve that the estimated values of these parameters are different for different histograms of TCT. Now, it is interesting to investigate that whether there is any significant trend between each parameter and traffic density. To this end, linear regression is carried out considering mean of each group of traffic density as independent variable and each parameter as a dependent one. The relationship between each parameter and mean vehicular density are presented in Eqs. (7)–(9). The plot between values of each parameter and corresponding vehicular densities are presented in Fig. 9. From regression analysis, it turns out that value of α is constant at 4 s irrespective of the vehicular density values. This indicates that the

Table 2
Estimation results of the fitted Pearson Type-III distribution and their χ^2 values against nine different range of vehicular traffic densities.

Vehicular density range in PCU/km	α	λ	K	χ^2 computed
10–30	3.99	1.73	7.42	11.64
30–50	4.00	1.48	7.16	13.85
50–70	4.00	1.41	7.58	8.23
70–90	4.00	1.33	7.56	9.69
90–110	4.00	1.22	7.87	10.63
110–130	4.00	1.29	8.01	13.56
130–150	4.00	1.18	8.09	11.12
150–170	4.00	1.17	8.03	5.99
170–190	4.00	1.23	8.88	10.68

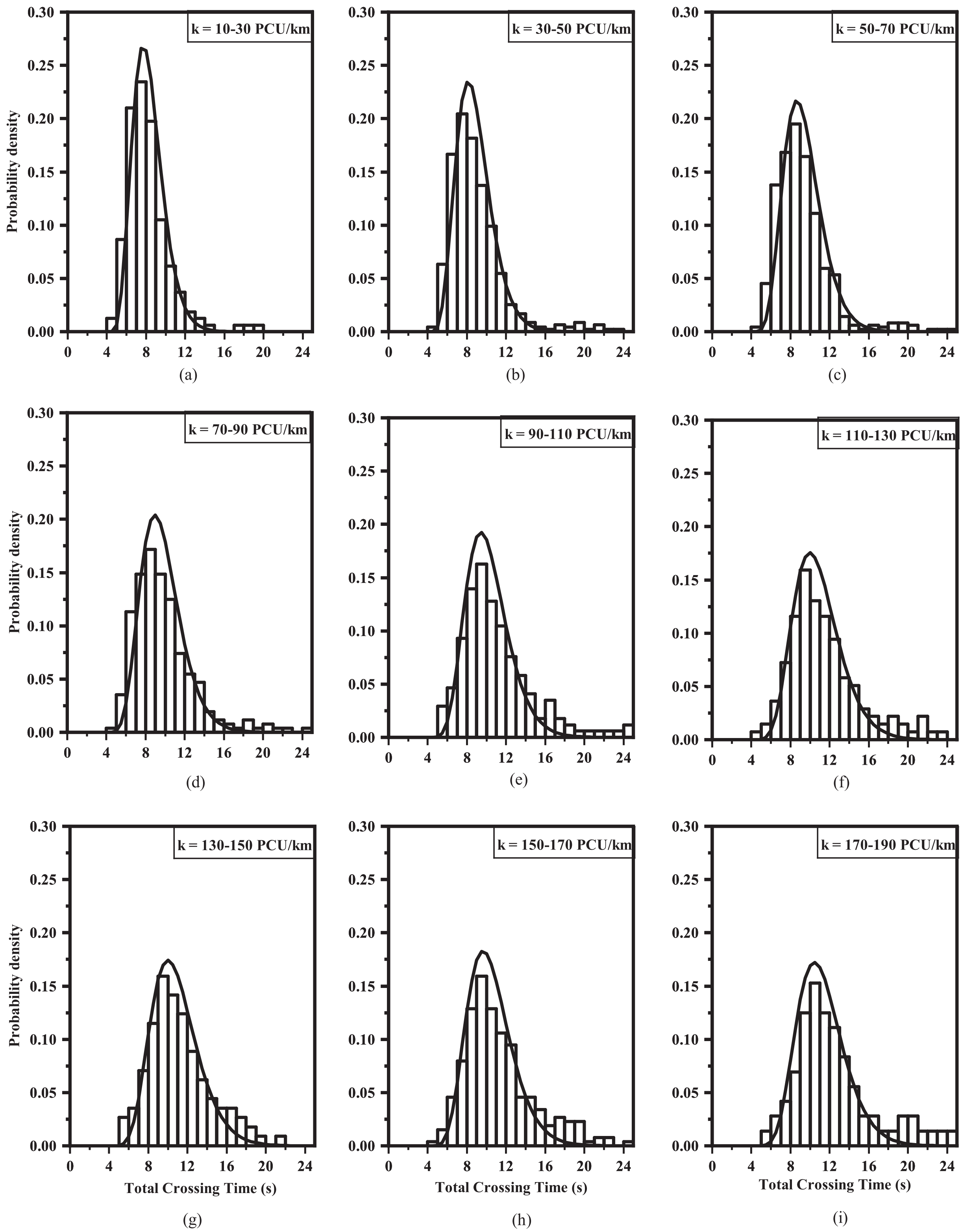

Fig. 7. Histograms of TCT distribution along with the fitted Pearson Type-III distribution against nine different ranges of traffic densities.

probability of TCT value of a TCT being less than 4 s is negligible. It can be said that this is the minimum time required by pedestrians to cross the road that is selected for the study.

It is shown in Fig. 5 that with the decrease in the value of λ, the sharpness of the curve, around the peak, goes down, and at the same time, peak also shifts towards right. The relationship that arises from the empirical study states that with the increase in traffic density, the value of λ is reducing. This means that as the density increases, more and more pedestrians start taking a longer time to cross the road. It is also shown in Fig. 5 that with the increase in K, the peak of the distribution shifts towards higher TCT values. From the empirical study, it can be stated that with an increase in density, the value of

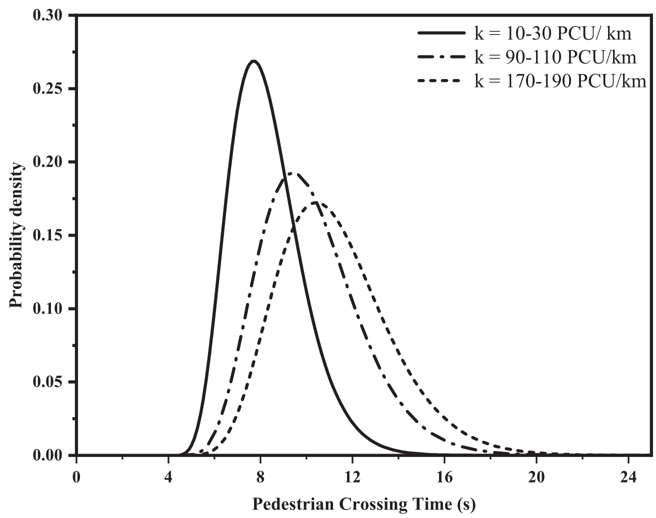

Fig. 8. Variation of fitted Pearson Type-III distribution against three different ranges of traffic densities.

K increases. This means that with an increase in traffic density, more number of pedestrians start taking a longer time to cross the road.

Summary

The location which a pedestrian selects to cross a road section can be of two types; and these are (i) at a nearby intersection, and (ii) at a mid-block section. This study focuses on the pedestrians crossing time at a mid-block section. Pedestrians while crossing a road sometimes have to wait or slow-down, in the middle of the road, for fear of conflict with the oncoming vehicles. The total duration of road crossing by a pedestrian includes initial waiting time as well as waiting in the middle of a road. In this study, the total duration taken by a pedestrian in crossing of a road is termed as Total Crossing Time (TCT). It is argued in this study that one should consider a distribution of TCT instead of considering a single value of TCT for a population of pedestrians. This indicates that TCT of each pedestrian can be different due to differences in their age, urgency, safety issues, gender, etc., while facing similar traffic stream. Therefore, considering a distribution of TCT instead of a single value of TCT is better to represent crossing time of pedestrians while facing even similar traffic streams. In order to model this, a reasonable traffic flow parameter that influences TCT distribution of pedestrians crossing a road is identified in this paper. This traffic flow parameter turns out to be the traffic density. It is understandable that pedestrians will perceive only a range of traffic density in place of a particular density value. Therefore, nine different classes of traffic density and its corresponding TCT distributions are computed. The TCT distributions are represented as histograms. These histograms are then fitted with Pearson Type-III and 3-parameter Weibull distributions. Pearson Type-III distribution turned out to be a better fit among the two distributions. It is observed from the fitted curves that with the increase in vehicular traffic density the peak in the TCT distributions shift towards higher TCT values. Further, with the increase in traffic density, size of the peak of TCT distributions reduces; and, with increase in density the curves also gets flatter. This indicates that one single value of TCT is a tenable idea if crossing of a road is taking place during less dense vehicular traffic. But, one has to consider a distribution of TCT and not a crisp value when pedestrians cross a road during highly dense traffic.

Although, Pearson Type-III distribution is fitted for all histograms, but the parameter values of the distribution are different for different classes of traffic density. This indicates that values of parameters are dependent on traffic density. Therefore, simple linear regression analyses are performed to find out the relationship between the values of parameters and corresponding traffic density. In this analysis, each parameter is treated as a dependent variable and traffic density as an independent one. The R^2 values are found to be in the range of 0.86 to 0.94 for the fitted curves. Of course, the regression models thus obtained cannot be directly used if number of lanes of the road and pedestrians are different than the one studied here. But, this study can be treated as a stepping stone in simulation of interaction between pedestrians and vehicular traffic streams. Having stated that, this study presents the empirical models that are estimated using data from just one site. But, according to (Chattaraj et al., 2009) pedestrian behavior generally remains same over a culture, so the proposed model should be applicable throughout India. Ofcourse, more investigations are required to establish the fact that whether the proposed models could also be used for homogeneous and lane based traffic. These limitations are the hurdles in directly using the empirical models presented in this study.

However, this study is useful to those Engineers and Scientists who would like to simulate crossing time of pedestrians at an uncontrolled mid-block section of a road with heterogeneous and non-lane based vehicular traffic. With the knowledge of prevailing traffic density, one can come up with the value of parameters of a TCT distribution

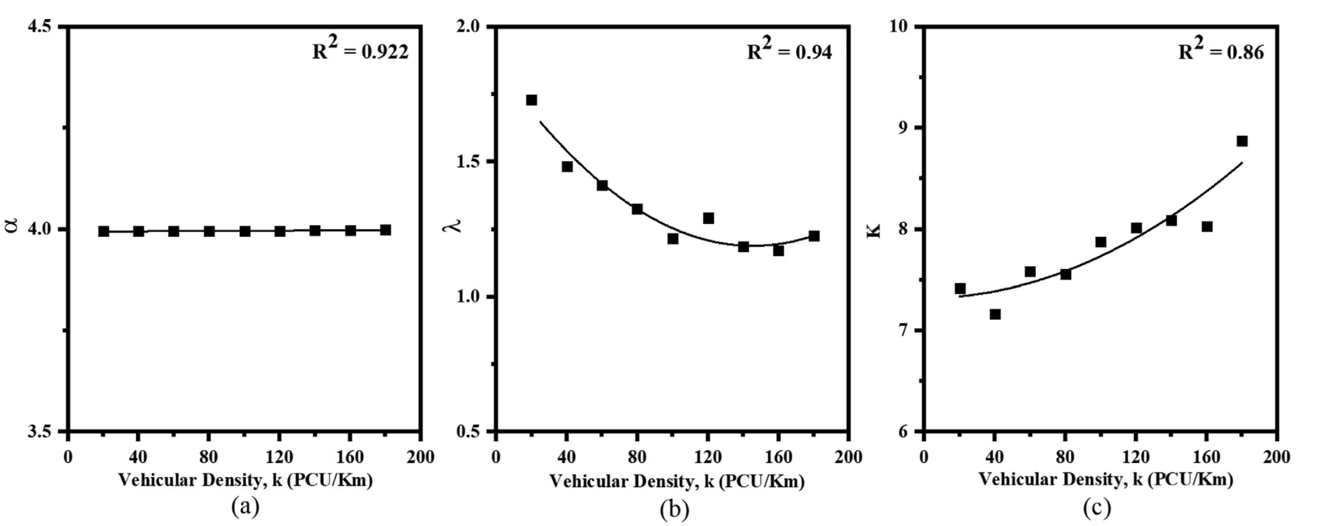

Fig. 9. Scatter plot of the parameter (a) α, (b) λ, and (c) K along with their respective estimated regression curves with traffic density.

by making use of the proposed empirical models. Since TCT values of pedestrians are stochastic in nature, using random numbers one can come up with TCT values for a population of pedestrians using the relevant TCT distribution.

CRediT authorship contribution statement

Somya Agarwal: Methodology, Software, Formal analysis, Investigation, Data curation, Writing - review & editing, Visualization. **Durgesh Vikram:** Conceptualization, Methodology, Resources, Writing - review & editing, Supervision.

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