Available online at www.sciencedirect.com
ScienceDirect
Transportation Research Part F 10 (2007) 77–89
TRANSPORTATION RESEARCH PART F
www.elsevier.com/locate/trf

Survival analysis: Pedestrian risk exposure at signalized intersections

Geetam Tiwari *, Shrikant Bangdiwala, Arvind Saraswat, Sushant Gaurav

Indian Institute of Technology, Delhi Transportation Research and Injury Prevention Programme, MS 808, TRIPP, IIT Delhi, Hauz Khas, Delhi 110016, India

Received 19 April 2005; received in revised form 3 February 2006; accepted 9 June 2006

Abstract

Pedestrian behaviour was observed at seven selected intersections in Delhi, India. Data collection occurred at these intersections by placing a video camera at each zebra crossing. Pedestrian crossing behaviour was then obtained from careful review of the videotapes. Pedestrian crossing behaviour was analyzed using survival analysis statistical methodology. The analyses produce Kaplan–Meier survival curves for waiting time prior to crossing unsafely, separately for males and females, and for each intersection. Mean observed waiting time and model-based waiting time of 90% of pedestrians were then studied. Mean waiting time of females are 27% more than for males, while the waiting time of 90% of female pedestrians are 44% more than the corresponding number for males. The probability for a pedestrian to cross the road, when it is unsafe, i.e. motor vehicles still have green or yellow, varies with waiting time. People do not want to wait too long to cross streets. As signal waiting time increases, pedestrians get impatient and violate the traffic signal. This violation places them at increased risk of being struck by a motor vehicle. Thus, reducing the waiting time for pedestrians are likely to decrease the probability of pedestrian crossers being hit by a motor vehicle.

Keywords: Pedestrian risk; Pedestrian delay; Intersection design; Survival analysis; Pedestrian safety

1. Introduction

The road network in Delhi is based on notional hierarchy of roads, ranging from arterial roads designed to carry fast through traffic to collector and residential roads. However, pedestrians are present on all roads regardless of the hierarchy and designated functions.

The existing road design does not provide adequate facilities for pedestrians, bicycles, or any other slow moving traffic. Service roads if present are not maintained well. Footpaths are either not present or poorly

* Corresponding author. Tel.: +91 11 26591047; fax: +91 11 26858703.
E-mail address: geetamt@gmail.com (G. Tiwari).

1369-8478/$ - see front matter
doi:10.1016/j.trf.2006.06.002

maintained. Approaches to bus stops, bus priority lanes, continuous pedestrian paths, lane for slow vehicles like bicycles and rickshaws etc. have not been included in the road network designs. Consequently all road users have to share the carriageway. This often leads to unsafe conditions for pedestrian and slow moving vehicles and congested conditions for motorized vehicles. State authorities and 'experts' continue to plan infrastructure, which ensures fast movement of car traffic at the cost of pedestrians, and non-motorized vehicles. However, restrictive measures for pedestrians are instituted such as high medians (30–50 cm) and fences on medians. At some locations pedestrian subways and foot over bridges have been provided to ensure that the pedestrians do not obstruct the motorized traffic. These poorly located pedestrian subways continue to have low usage rate not only because of poor location but also because of safety concerns and they are often locked at night. This leaves no option for pedestrians but to either break the median fences or run across the road under unsafe conditions.

In Delhi, pedestrians, bicyclists and motorized two wheelers (MTWs) constitute 75% of the total fatalities in road traffic crashes. Because bicyclists and pedestrians continue to share the road space in the absence of infrastructure specifically designed for non motorized vehicles (NMVs), they are exposed to higher risks of being involved in a road traffic accident by sharing the road space with high-speed modes. Fig. 1 shows road traffic fatalities in Delhi from 1990 to 2004 (Road Accidents in Delhi, 2003). Pedestrians are the largest shares in total fatalities. The most alarming trend is that this share has been increasing over the years compared to other victims. Buses and trucks are involved in more than 60% of the fatal crashes.

A study of midblock conflicts at fourteen sites studied by us show that maximum mixing of pedestrians, non-motorized vehicles (NMVs) and motorized vehicles (MVs) occurs at the bus stops (Tiwari, Mohan, & Fazio, 1998). Their interaction with other MVs is minimal at other locations. In three lane roads, MVs use two lanes and the curbside lane is used by NMVs. Though de facto segregation takes place on two and three lane roads, an unacceptable danger exists to pedestrians and bicyclists because of conflict with MVs.

Hamed (2001) studied the factors that influence a pedestrian's waiting time and frequency of attempts to cross streets. He found that the pedestrians' expected waiting time has profound influence on the number of attempts needed to successfully cross the street. Hamed reports that pedestrians who frequently use a cer-

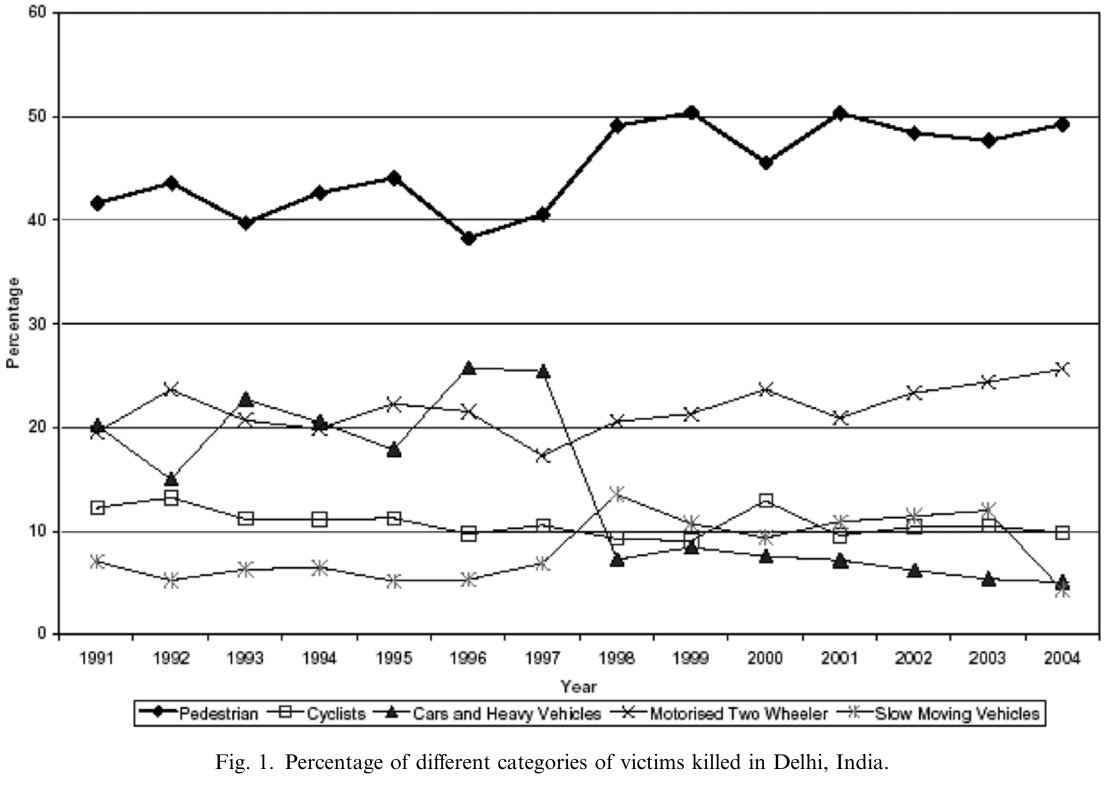

Fig. 1. Percentage of different categories of victims killed in Delhi, India.

tain pedestrian crossing and who live nearby the crossing are likely to accept higher risk and reduce their waiting time at pedestrian crossings. On the other hand, a pedestrian's past involvement in a traffic crash seems to inhibit the pedestrian from accepting higher risk. Hamed also found that pedestrians who spend more time waiting to cross from one side of the street to central refuge are likely to have a higher risk of ending their waiting time as they cross from central refuge to the other side of the street.

Sisiopiku and Akin (2003) findings from a user survey and observational study of pedestrian behaviours at various urban crosswalks concluded that signalized intersections with crosswalks help channelize pedestrian traffic; however, these crosswalks prove to be unable to persuade pedestrians to comply with the signal indication, particularly under low traffic demand conditions. Properly designed and placed pedestrian facilities encourage users to cross at specific locations. The most influential factor cited by pedestrians in making a decision to cross at a designated crossing location is the distance of the crosswalk to desired location.

Leden (2002) found that risk for pedestrians decreased with increasing pedestrian flows and increased with increasing vehicle flow. Leden suggested that one explanation could be increased driver alertness. As the risk decreases with increasing pedestrian flows, promoting walking will have a positive effect on pedestrian risk at signalized intersections. However, an increased pedestrian flow might lead to more pedestrian crashes if promotion is not accompanied by appropriate safety measures, such as speed-reducing devices and increased surveillance of red light running and walking.

Diaz (2002) reported that young people are more likely to commit violations as pedestrians than adults. Men commit more frequent violations of traffic rules than women do.

Tanaboriboon and Jing (1994) compared signalized intersection pedestrian crossings to overpass and underpass counterparts in Beijing, China, and found that pedestrians preferred the signalized crossings to the overpass or underpass crossings.

Rouphail (1984) performed a user compliance and preference study on marked midblock crosswalks in downtown Columbus, Ohio. He concluded that users perceived the unsignalized marked midblock crosswalk to be unsafe. But, the same crosswalks were found to be most convenient.

Carsten, Sherborne, and Rothengatter (1998) compared the pedestrian wait time at three sites before and after construction of innovative pedestrian signalized crossing. They observed that pedestrians are impatient while doing the second half of the crossing. They also found that there were general gains in safety and comfort for pedestrians and these improvements were obtained without major side effects on vehicle travel.

This paper reports the results of pedestrian behaviour at intersections in Delhi, India to understand how intersection environment could be improved to facilitate pedestrian movement.

2. Method

Pedestrian behaviour was observed at seven selected intersections in Delhi, India. Data collection occurred at these intersections by placing a video camera at each zebra crossing. Pedestrian crossing behaviour was then obtained from careful review of the videotapes. Fig. 2 shows photograph of pedestrian crossing at AIIMS intersection as an illustration. At each intersection, installation of one video camera covered one major zebra crossing. High-quality Umatic digital cameras equipped with a frame-by-frame timer (25 frames/s), were used for the study. The position and direction of the video camera installed at these intersections is shown in the schematic intersection drawing in Fig. 3. For each intersection separately, we studied the pedestrians moving between Point 1 and Point 3. All the intersections that were studied are signalized intersections. Each intersection has medians and zebra crossings as shown in Fig. 3.

Pedestrian crossing behaviour was analyzed using survival analysis statistical methodology. Singer and Willet (1993) demonstrated empirically and mathematically how the set of statistical methods known as discrete-time survival analysis provide an ideal framework for modelling the relationship between event occurrence and predictors. They took a simple example of all special educators hired in Michigan between 1972 and 1978 for the purpose of plotting survivor function and tried to describe the distribution of those special educators' careers. They also provided illustrative computer code for fitting discrete-time hazard models and for recapturing fitted hazard and survival functions. We have not found application of this technique for the purpose of studying pedestrian crossing behaviour in published articles. However, it is being widely used in the field of medical science.

Fig. 2. Photograph of pedestrian crossing at AIIMS intersection.

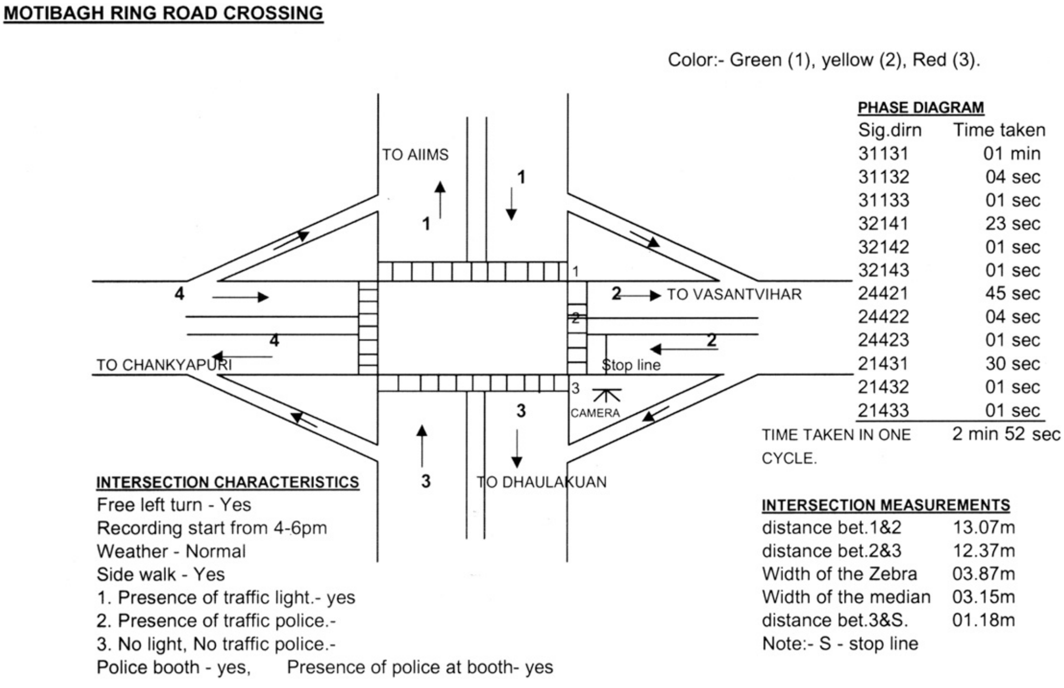

Fig. 3. Schematic intersection.

2.1. Field work

Table 1 gives brief description of the intersections. They represent a range of environmental factors and all the seven intersections represent relatively different environments, and that forms the merit for their selection. Of the seven intersections, four are four armed intersections and three are three armed intersections. All the intersections are signalized and have free-left turns. Each intersection has a median which is around 30–40 cm in height and less than 1 metre wide. Thus the medians cannot be used by pedestrian as a safe refuge.

Table 1
Description of intersections

S. No.	Intersection	Description	Cycle time (s)	Number of phases
1	Africa avenue ring road crossing	It is a four-arm intersection, two major arterial roads cross. An important market on one side of the intersection and s a bus stop also. Four free left turns present	220	5
2	AIIMS ring road crossing	Four-arm intersection, two major arterial roads cross. Two big hospitals on two sides of the intersection, and two major bus stops, leading to presence of large number pedestrians. Four free left turns	185	4
3	ITO crossing	Four-arm intersection, two major arterial roads cross. Important offices on two sides of the intersection. Two major and one minor bus stop. Large number of commuters board or alight buses here. Side walk exists on one side of the intersection. Three free left turns	285	5
4	Khalsa college ring road crossing	Three arm-intersection, two major arterial roads meet. A college on one side of the intersection, one bus stop. Side walk exists on one side of the intersection. Two free left turns	91	3
5	Lakshminagar crossing	Four-arm intersection, two major arterial roads meet. Large number of shops near the intersection, two bus stops. Side walk exists on one side of the intersection. Two free left turns	170	4
6	Motibagh ring road crossing	Four-arm intersection, two major arterial roads cross. This is a less busy intersection. Two bus stops and four free left turns. Medians exist at all the arms of all the seven intersection	172	4
7	Panchsheel T-type crossing	A three-arm intersection, where two major arterial roads meet. Two free left turns	180	3

2.2. Coding of videotape data

Videotape data were coded in the laboratory. Frame by frame progress of tapes was monitored by research assistants manually, and values entered in a pre-designed format. Two data files were made for each intersection, one for pedestrian and the other for vehicles that potentially conflicted with some pedestrians. Only pedestrian files have been used in this analysis. The following sets of variables from the pedestrian file have been used:

Peak coded 1 for peak hour, 0 otherwise
S arrival signal direction at arrival. A five digit code to show traffic flowing in two directions: first and the second digits are respectively the directions of origin and destination for the first set, third and fourth are the corresponding ones for the second set, the last digit is the colour of signal
T arrival time at which *S arrival* begins. When taping starts at the middle of a cycle this variable is set equal to zero
S depart signal at departure from origin
T depart time at which *S depart* begins
Sex one males, two females
Age one child, two youth, three middle aged, four old
TAO time of arrival at origin in frames, i.e., point 1
Drctn. first digit is origin of pedestrian and second digit is destination direction of pedestrian
TDO time of departure from origin, i.e., point 1
TAI2 time of arrival at intermediate point 2
TDI2 time of departure from intermediate point 2

2.3. Statistical analysis

2.3.1. Survival analysis

Each person's crossing behaviour was calculated. Fig. 4a and b illustrates schematically the calculation of the waiting time to unsafe crossing. An unsafe crossing is when a pedestrian crosses when the traffic signal indicates GREEN or YELLOW for the motorized vehicle traffic. If the pedestrian starts crossing the road during this time the pedestrian is considered to be at risk. This risk is called an event. But before crossing the pedestrian waits for some time. This time is called the waiting time and is equal to the difference of the time at which pedestrian arrives and the time at which he or she leaves the origin. For studying the event of time to unsafe crossing, we consider only persons that arrive during the unsafe crossing period; thus, person F is not included in our analyses. We actually only observe the minimum of the waiting time to crossing and the censoring time, or the time point at which it has become safe to cross – RED signal for the traffic. Thus, persons A, B, C, D, E are eligible for our study since they arrive during the unsafe period. However, persons A and E wait until the safe crossing period to cross, so, that their time to *unsafe* crossing is considered censored at the moment that the unsafe crossing period ends.

Fig. 4b illustrates how the waiting times are used in the analysis – waiting times are shifted to a common origin, and subjects A and E are considered censored, while for subjects B, C, D we have been able to observe their time to unsafe crossing.

The fields of actuarial science and clinical epidemiology make much use of survival analysis or the study of the times to the unique occurrence of an event. We have used survival analysis in our context, where we are interested in the time to the occurrence of the event of crossing unsafely (green or yellow light signal for the motor vehicle traffic). It occurs only once for a particular subject. For the purpose of studying pedestrian crossing behaviour, the definition of '*event*' is a crossing of the road when the traffic signal indicates GREEN or YELLOW for motor traffic and RED for the pedestrian. Once the pedestrian begins crossing, the event occurs. If the pedestrian crosses at the safe time, their waiting time until the beginning of the safe crossing period is used and their time to unsafe crossing is considered censored. The unadjusted nonparametric Kaplan and Meier (1958) estimate of the survival curve accounts for the censoring in estimating the probability of not having crossed unsafely by a given time point t. The Kaplan–Meier estimated survival curve is simply defined as

$$S_{\mathrm{KM}}[t(i)] = \prod_{j^*}\{1 - d(j)/r(j)\},$$

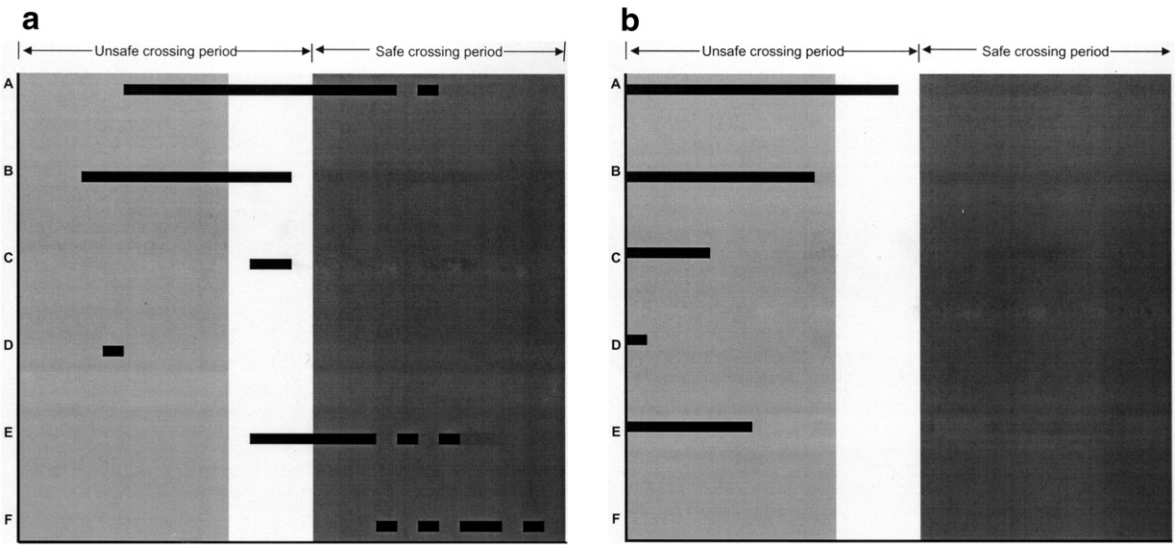

Fig. 4. Schematic diagram of time to unsafe crossing.

where j^* is the set j such that $t(j) < t(i)$, $d(j)$ is the number of events at time $t(j)$, and $r(j)$ is the number at risk (those who have not yet crossed unsafely or those whose time to unsafe crossing is censored).

The estimated K–M curve can be adjusted for the effects of covariates, either by stratified analysis or by modelling. The proportional hazards regression model of Cox (1972) is typically used to model survival times adjusting for multiple covariates. In our study, we adjust only for gender of the pedestrian, using stratified analysis. All calculations were done with SYSTAT 8.0.

2.3.1.1. Survival analysis variables. The 'time to unsafe crossing' survival variable is a measurement of time for which negative or zero values would be meaningless. Some pedestrians do not wait before crossing, i.e. they arrive at the intersection and cross with only a cursory non-measurable stop. In order to include them in the analysis, since the precision of our time measuring device is 0.04 s, these pedestrians were assigned waiting times of 0.039 s. The pedestrian with the above coded wait time are said to have negligible wait time.

The censoring variable is a binary indicator variable, coded a '0' for waiting times that are censored (pedestrian crosses safely) and '1' for waiting times that are observed (pedestrian crosses unsafely).

Table 2 shows a sample data set of nine pedestrians as an example. The wait time column of Table 2 contains the waiting time of pedestrians before they start to cross the road. In the censor column, censor variable is coded '1' for the pedestrians doing unsafe crossing with corresponding waiting time in the wait time column. The censor variable is coded '0' for the pedestrians who cross the road when the traffic signal indication turns green for pedestrian and who arrived when the traffic signal indication was red for pedestrians. They are included in analysis despite doing safe crossing because they waited during the red time interval and were exposed to risk during that time interval. Table 2 goes as an input for survival analysis. The methodology and results of calculations are illustrated in Table 3. Fig. 5 shows survival plot for the example. The time coordinate of survival plot is time interval column of Table 3 and KM Probability column of Table 3 is the survivor function coordinate of survival plot. Survival plot gives us the probability at time '*t*' that a pedestrian would initiate an unsafe crossing.

Table 2
Sample data set for survival analysis

Censor	Wait time
1	0.039
1	0.039
1	0.039
1	0.039
0	3
1	2.2
1	17.24
1	17.24
1	0.88

Table 3
Sample calculations for survival analysis

Wait time interval	Number of pedestrians waiting	Number of pedestrians censored	Number of pedestrians at risk	Number of pedestrians crossing unsafely	Proportion of pedestrian waiting	KM probability or probability of survival
0–0.039	9	0	9	4	$(9-4)/9 = 0.556$	**0.556**
0.039–0.88	5	0	5	1	$(5-1)/5 = 0.8$	$0.556 * 0.8 =$ **0.445**
0.88–2.2	4	0	4	1	$(4-1)/4 = 0.75$	$0.556 *0.8 * 0.75 =$ **0.333**
2.2–3	3	1	3	0	$(3-0)/3 = 1$	$0.556 * 0.8 * 0.75 * 1 =$ **0.333**
3–17.24	2	0	2	2	$(2-2)/2 = 0$	$0.556 * 0.8 * 0.75 *1 * 0 =$ **0**

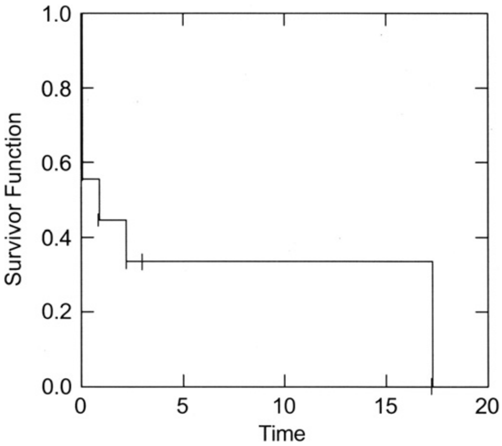

Fig. 5. Survival plot for sample calculations.

2.3.2. Correlation analyses

We studied the correlation between pedestrian delay at each intersection, between points marked 1 and 3, and the mean survival times for both males and females. Spearman's rank correlation coefficient was used for the purpose since we did not expect to have Gaussian distributions for the data. The Spearman rank correlation coefficient, in the absence of ties in the data, is calculated according to the equation

$$R_s = 1 - \left(6\sum_{n}^{i=1} d_i^2\right) \Big/ (n^3 - n),$$

where d_i is the difference between ranks for each (x_i, y_i) data pair and n is the number of data pairs.

We ranked according to the magnitude of variables between which correlation is to be calculated. The correlation is calculated between mean survival time and pedestrian delays for full crossing situations. The correlation is also calculated between time to unsafe crossing of 90% of pedestrians and pedestrian delays for full crossing. Full crossing denotes traversing the full width of the road, i.e. from 1 to 3, (excluding median width) as shown in Fig. 3. Half crossing is traversing the width from one side of the road to the median, i.e. from 2 to 3 as shown in Fig. 3.

Pedestrian delay is defined as the average delay experienced by the pedestrian while crossing the intersection. It depends on the characteristics of the intersection in consideration, and is dependent on the geometry of the intersection and the signal timing of the intersections. Pedestrian delay is given by

$$\text{Pedestrian Delay} = 0.5 * (C - G_e)^2/C \quad (\text{HCM, 2000}),$$

where C = cycle length in seconds, and G_e = effective green time. Now, $G_e = G - W$, where G = green time for pedestrian, and W = time taken for the pedestrian to cross the road with the speed of 1 m/s.

3. Results

Table 4 shows pedestrian delay at selected intersections for full-crossings. The pedestrian delay varies from 43.4 s at Panchsheel to 152.7 s at ITO. Pedestrian delay has been explained in Section 2.3.2. The cycle time varies from 91 s at Khalsa to 285 s at ITO. Out of the seven intersections at ITO, Khalsa and Lakshminagar pedestrians cannot make a safe full crossing, which is attributed to the fact that the total green time for pedestrians is less than the time taken to cross the road at speed of 1 m/s.

Table 5 gives pedestrian delays for half-crossings for the seven intersections. Cycle times, number of phases, green times for pedestrians, width and effective green times for pedestrians are also given. Pedestrian delays for half-crossings vary from 3.2 s at Panchsheel intersection to 129.1 s at ITO intersection. The widths for half-crossings vary from 7.01 m at Panchsheel intersection to 14.75 m at ITO intersection.

Table 4
Pedestrian delay at selected intersections for full-crossing

Name of the sites	Cycle time (s)	Number of phases	For full crossing (1–3) (time, s)				
			Total green for pedestrians	% Green in total cycle time	Width (m)	Effective green time	Pedestrian delay
1. Africa Avenue	220	5	78	35.2	20.0	58.0	59.6
2. AIIMS	185	4	62.5	33.8	27.9	34.6	61.2
3. ITO	285	5	16	5.6	26.1	−10.1	152.7
4. Khalsa	91	3	0	0.0	21.1	−21.1	69.0
5. Lakshminagar	170	4	20	11.8	26.7	−6.7	91.8
6. Motibagh	172	4	65	37.8	24.7	40.3	50.5
7. Panchsheel	180	3	70	38.9	15.0	55.0	43.4

Table 5
Pedestrian delay at selected intersections for half-crossings

Name of the sites	Cycle time (s)	Number of phases	For half-crossing (1–2) (time, s)					For half-crossing (2–3) (time, s)				
			Total green for pedestrians	% Green in total cycle time	Width (m)	Effective green time	Pedestrian delay	Total green for pedestrians	% Green in total cycle time	Width (m)	Effective green time	Pedestrian delay
1. Africa avenue	220	5	165	75.0	10	159	8.5	169	76.8	10	96.2	7.4
2. AIIMS	185	4	88.5	47.8	14.51	77.99	31	97.5	52.7	13.41	48.8	25.4
3. ITO	285	5	21	7.4	11.31	13.69	129.1	205	71.9	14.75	137.1	14.4
4. Khalsa	91	3	45	49.5	10.52	38.48	15.16	46	50.5	10.58	−0.55	14.62
5. Lakshminagar	170	4	20	11.8	14.63	9.37	75.9	100	58.8	12.07	45.2	17.9
6. Motibagh	172	4	97	56.4	13.07	87.93	20.5	90	52.3	12.37	41.7	23.7
7. Panchsheel	180	3	100	55.6	7.01	96.99	19.1	150	83.3	8.02	70.7	3.2

Table 6 gives the number of full and half crossing pedestrians in respective directions. Section 2.3.2 and Fig. 3 define full and half crossing. In case of safe crossing, the number of full crossing pedestrians is much higher than the number of half crossing pedestrians at all intersections, except at Khalsa and Lakshminagar where the number of pedestrians in direction 2–3 (half-crossing) is higher. For unsafe crossing also the number of full crossings is much higher than half crossings, except at Khalsa where the number of half crossing (2–3) pedestrians is marginally above the number of full crossing pedestrians. The variation in percentage of unsafe full crossings is from 29.4% at AIIMS to 91.1% at ITO. Here we have ignored the Khalsa intersection because the number of data points is low; there are no safe full crossings and eight unsafe full crossings, which makes the percentage of unsafe crossings 100%. The percentage of unsafe full crossings is more than 80% at ITO, Khalsa and Lakshminagar, which could be attributed to the fact that the time required for a safe full crossing is less than the green time for pedestrians. Khalsa is a T-type intersection and it is not possible to make a safe crossing in direction 1–2 (half crossing) and thereby it is also not possible to make a safe full crossing (1–3)

Table 6
Number of full crossing and half-crossing pedestrians

Name of the sites	Number of pedestrians doing safe crossing in respective directions			Number of pedestrians doing unsafe crossing in respective directions			% Unsafe in full crossing (1–3)
	1–3 (full)	1–2 (half)	2–3 (half)	1–3 (full)	1–2 (half)	2–3 (half)	
1. Africa avenue	216	0	1	236	0	0	52.2
2. AIIMS	392	23	30	196	2	7	33.3
3. ITO	20	0	1	205	3	6	91.1
4. Khalsa	0	0	47	8	1	10	100.0
5. Lakshminagar	16	1	97	90	0	74	84.9
6. Motibagh	46	0	3	75	0	1	62.0
7. Panchsheel	39	0	0	22	0	0	36.1

because the green time is zero for pedestrians. This fact is also supported by data that there is no safe full or half crossings at Khalsa. Carsten et al. (1998) concluded that pedestrians are better capable of judging crossing possibilities at the first stage of crossing than at the second stage and therefore recommended that crossings should be made at two distinct stages, i.e., waiting at central reserve. Our study supports this finding, as the number of unsafe half-crossing is greater in second half, i.e., from point 2 to point 3; when compared with first half i.e. from point 1 to point 2. Table 6 shows the observed number of pedestrians doing half-crossings is small. Therefore one cannot use it for statistical analysis. Large number of pedestrians were observed to be doing unsafe full-crossing, thus unsafe full-crossings were used for the purpose of survival analysis.

Fig. 6 shows survival plot for all males taken together and all females taken together. The plot shows how the probability of survival varies with time for males and females. Here both censored and uncensored variables have been used for plotting this graph. The graph indicates that probability of survival for males is less than that for females at all times.

Table 7 shows results of survival analysis when the data excluded the censored variables i.e. only unsafe crossings are included. Censoring has been explained in Section 2.3.1. Pedestrians making unsafe crossing (with negligible wait time), varies from 50% at Khalsa to 80.3% at Africa Avenue. It is to be noted that at Khalsa and Panchsheel the number of data points are less than 23. Therefore, the number of pedestrians with negligible wait time is uniformly high. The survival time of 90% of pedestrians is uniform at all intersections except at ITO (31.4 s), and varies from 8.2 s at Africa Avenue to 18.6 s at Lakshminagar.

Table 8 gives the numbers and percentage of pedestrians for corresponding intervals of waiting time, 84.1% pedestrian were observed to have waiting time of less than 10 s.

Table 9 shows the results of survival analysis when the data included both censored and uncensored variables. The results are similar to those in Table 7 because the number of censored variables is very small. The percentage of pedestrians making unsafe crossing, with negligible wait time, with respect to total number of

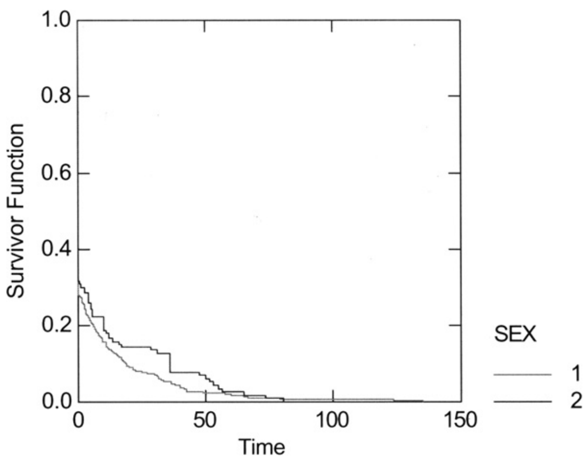

Fig. 6. Survival plot for all males taken together and females taken together.

Table 7
Waiting time distribution for pedestrians

Waiting time (s)	Number of pedestrians	Percentage
0–10	687	84.1
10–20	55	6.7
20–30	18	2.2
30–40	27	3.3
40–50	12	1.5
50–Highest	18	2.2

Table 8
Pedestrian characteristics at the signalized intersections (without censor)

Name of the sites	Total number of pedestrians crossing		Number and % of total of pedestrian crossing from 1 to 3 with negligible wait time						Survival time of pedestrians from 1 to 3 (s)								
			Males		Females		All ped.		Males			Females			All pedestrians		
	Males	Females	Num.	%	Num.	%	Num.	%	90%	Mean	Max.	90%	Mean	Max.	90%	Mean	Max.
1. Africa avenue	202	36	163	80.7	28	77.8	191	80.3	8.4	2.5	42.5	3.2	2.6	64.9	8.2	2.5	64.9
2. AIIMS	133	30	103	77.4	24	80.0	127	77.9	17.8	4.7	66.3	31.2	6.8	55.1	18.9	5.1	66.3
3. ITO	160	44	108	67.5	25	56.8	133	65.2	23.9	7.8	135.4	35.9	6.8	73.2	31.4	8.3	135.4
4. Khalsa	5	3	3	60.0	1	33.3	4	50.0	17.2	3.9	17.2	17.2	6.0	17.2	17.2	4.7	17.2
5. Lakshminagar	72	18	50	69.4	12	66.7	62	68.9	17.0	4.0	39.6	28.4	10.7	80.5	18.6	5.3	80.5
6. Motibagh	69	6	45	65.2	3	50.0	48	64.0	11.6	4.3	40.0	16.6	6.0	16.4	13.2	4.4	40.0
7. Panchsheel	22	0	11	50.0	0	0.0	11	50.0	16.3	7.6	53.8	NA	NA	NA	16.3	17.6	53.8
8. Total	663	137	483.0	72.9	93	67.9	576	72.0	15.9	4.8	135.4	31.2	8.1	80.5	17.0	5.2	135.4

Table 9
Pedestrian characteristics at the signalized intersections (with censor)

Name of the sites	Total number of pedestrians crossing		Number and % of total of pedestrian crossing from 1 to 3 with negligible wait time						Survival time of pedestrians from 1 to 3 (s)								
			Males		Females		All pedestrians		Males			Females			All pedestrians		
	Males	Females	Num.	%	Num.	%	Num.	%	90%	Mean	Max.	90%	Mean	Max.	90%	Mean	Max.
1. Africa avenue	210	36	163	77.6	28	77.8	191	77.6	13.9	3.8	42.4	3.1	2.6	64.9	12.3	3.8	64.9
2. AIIMS	136	31	103	75.7	24	77.4	127	76.0	25.3	5.5	66.2	31.2	8.1	55.1	30.5	6.0	66.2
3. ITO	160	44	108	67.5	25	56.8	133	65.2	23.9	7.8	135.4	35.9	10.0	73.2	31.4	8.3	135.4
4. Khalsa	5	3	3	60.0	1	33.3	4	50.0	17.2	3.9	17.2	17.2	6.1	17.2	17.2	4.7	17.2
5. Lakshminagar	73	18	50	68.5	12	66.7	62	68.1	17.0	4.2	39.6	22.4	10.7	80.5	18.6	5.5	80.5
6. Motibagh	69	6	45	65.2	3	50.0	48	64.0	11.6	4.3	40.0	16.4	6.0	16.4	13.2	4.4	40.0
7. Panchsheel	34	2	11	32.4	0	0.0	11	30.6	21.5	10.8	53.8	NA	NA	NA	21.5	13.7	53.8
8. Total	687	140	483	70.3	93	66.4	576	69.6	18.8	5.6	135.4	31.2	8.1	80.5	19.2	6.0	135.4

pedestrians, varies from 50% at Khalsa to 77.6% at Africa Avenue. The survival time of 90% of pedestrians varies from 12.3 s at Africa Avenue to 31.4 s at ITO.

Table 10 shows correlations between pedestrian delay and survival times. The correlation between pedestrian delay and survival time of 90% pedestrians is +0.86. As the pedestrian delay increases the survival time of pedestrians also increases. This is because the percentage of pedestrians having negligible wait time is high, and pedestrians who wait tend to wait even longer. The correlation between pedestrian delays and percentage of people doing unsafe crossing is found to be +0.63. Therefore as pedestrian delay increases the percentage of unsafe crossings also increase.

Table 10
Correlation between pedestrian delay and survival times

MALE 90% S.T.	+.74
MALE MEAN S.T.	+.41
FEMALE 90% S.T.	+.66
FEMALE MEAN S.T.	+.34
ALL 90% S.T.	+.86
ALL MEAN S.T.	−.08
% NEG. S.T.	+.10
% UNSAFE CR.	+.63

MALE 90% S.T.: time when 90% of males have crossed, MALE MEAN S.T.: mean survival time of males, FEMALE 90% S.T.: time when 90% of females have crossed, FEMALE MEAN S.T.: mean survival time of females, ALL 90% S.T.: time when 90% of pedestrians have crossed, ALL MEAN S.T.: mean survival time of all pedestrians, % NEG. S.T.: percentage of pedestrians with negligible wait time, % UNSAFE CR.: percentage of pedestrians making unsafe crossing in 1–3 direction.

4. Discussion and conclusions

This helps us understand the effect of intersection geometry, traffic flow pattern and traffic management on pedestrian crossing behaviour at signalized intersections. Signalized intersections have been chosen because 40% of crashes involving pedestrians occur there (Tiwari et al., 1998). Survival analysis has been used to find correlation between the wait time of pedestrians facing unsafe crossing environment and pedestrian delay. In medical science survival analysis is used to study the effectiveness of different drugs on cancer patients. We have used survival analysis to estimate how the risk that occurs to pedestrians varies with time.

Our results show that number of persons doing unsafe full crossings and safe half crossings is high (up to 90% and 85% respectively). This study included divided roads with medians. However the medians are usually 45 cm high and not convenient for pedestrian use. At some places a barbed fence is constructed to discourage people from crossing the road. It seems that pedestrians are crossing half the road and waiting at the median, else they are crossing the full road under unsafe conditions. The effective green time at many intersections is less than the minimum time required for crossing the given road width. This explains why there are higher numbers of pedestrians attempting full crossing, are doing so under unsafe conditions. This implies that the existing signal phasing does not account for pedestrian crossings. Providing safe pedestrian crossing environment requires that each phase of the signal cycle should be checked against the minimum time required by pedestrians for crossing that section.

Contrary to general belief that pedestrians take unnecessary risk and indulge in jaywalking, our study shows that majority of the pedestrians prefer crossing half the road under safe conditions. This has an important message for road designers that at all major roads, to encourage safe crossings, scientifically designed medians and safe refuge islands for pedestrians should be provided.

The results of survival analysis indicate that the mean waiting time for females are 27% more than for males, while the waiting time of 90% of female pedestrians are 44% more than the corresponding number for male. This confirms the findings of earlier study by Diaz (2002) which reported that male pedestrians commit more frequent violations of traffic rules than female pedestrians do.

There are a large number of people with negligible wait time, there are only few who wait and wait longer, and they are generally non-risk takers. This goes on explaining the correlation of +0.86 between pedestrian delay and 90% survival time, which is contrary to the hypothesis in HCM (2000). HCM (2000) states that when pedestrians experience more than a 30 s delay, they become impatient and engage in risk taking behaviour. Since data used for survival analysis includes pedestrians facing unsafe conditions only, the correlation indicates that people who become impatient because of long delays are not willing to wait at all. The remaining pedestrians are risk averse and are waiting longer at the intersection having higher pedestrian delays. Clearly higher pedestrian delays at the intersection result in higher number of unsafe crossings.

We conclude that safe pedestrian behaviour at signalized intersections can be encouraged by making changes in the intersection geometry and signal cycle timings. This will reduce incidence of jaywalking and the risk that occurs to pedestrians.

Acknowledgements

This work was supported by grants from Society of Indian Automobile Manufacturers and Volvo Research and Educational Foundation.

References

Carsten, O. M. J., Sherborne, D. J., & Rothengatter, J. A. (1998). Intelligent traffic signals for pedestrians: evaluation of trials in three countries. *Transportation Research Part C, 6*, 213–229.

Cox, D. R. (1972). Regression models and life tables. *Journal of the Royal Statistical Society, Series B, 34*, 187–220.

Diaz, E. M. (2002). Theory of planned behavior and pedestrians' intentions to violate traffic regulations. *Transportation Research Part F, 5*, 169–175.

Hamed, M. M. (2001). Analysis of pedestrian's behavior at pedestrian crossings. *Safety Science, 38*, 63–82.

Highway Capacity Manual (2000). National Research Council, Washington, DC.

Kaplan, E. L., & Meier, P. (1958). Nonparametric estimation from incomplete observations. *Journal of the American Statistical Association, 53*, 457–481.

Leden, L. (2002). Pedestrian risk decrease with pedestrian flow. A case study based on data from signalized intersections in Hamilton, Ontario. *Accident Analysis and Prevention, 34*, 457–464.

Road accidents in Delhi (2003). Delhi Traffic Police, New Delhi, India.

Rouphail, N. M. (1984). Midblock crosswalks: a user compliance and preference study. *Transportation Research Record, 959*, 41–47.

Singer, J. D., & Willet, J. B. (1993). It's about time: using discrete-time survival analysis to study duration and the timing of events. *Journal of Educational Statistics, 18*, 155–195.

Sisiopiku, V. P., & Akin, D. (2003). Pedestrian behavior and perceptions towards various pedestrian facilities: an examination based on observation and survey data. *Transportation Research Part F, 6*, 249–274.

Tanaboriboon, Y., & Jing, Q. (1994). Chinese pedestrians and their walking characteristics: case study in Beijing. *Transportation Research Record, 1441*, 16–26.

Tiwari, G., Mohan, D., & Fazio, J. (1998). Conflict analysis for prediction of fatal crash locations in mixed traffic streams. *Accident Analysis and Prevention, 30*(2), 207–215.