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Pedestrian Delay Modeling at Signalized Crosswalks at Mixed-Traffic Intersections

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Abstract

Because of its adaptability and portability, walking is a primary and sustainable means of urban transit in India. Crossing at signalized intersections with mixed traffic poses challenges for pedestrians. When crossing at a signalized junction, pedestrian latency is the biggest issue. Significant, but hard to quantify, parameter. With this in mind, the purpose of this study was to create a pedestrian delay model for crosswalks at signalized intersections. From a video survey of a standard four-arm signalized crossroads in Mumbai, India, we were able to extract the necessary model parameters. Some interesting findings emerged from the analysis of the field data, including: Some pedestrians crossed the crosswalk during the flashing red signal phase and the red phase, indicating that pedestrians adapt their crossing pace to the current traffic conditions. A novel delay model appropriate for the Indian context was established on the basis of three factors: the delay in waiting, the delay in crossing, and the delay in pedestrian-vehicular interaction.

1. Introduction

The number of pedestrians killed in traffic accidents in most Indian cities is shockingly high. According to recent data that tracks emergencies at pedestrian crossings; inadequate maintenance and lack of planning have created a serious problem for traffic safety in Mumbai. At crosswalks with traffic signals in the presence of both pedestrians and vehicles. The pedestrian delay at a signalized junction crossing is a major issue for pedestrians and is notoriously difficult to predict. The majority of transportation studies have focused only on travel time delays at signalized junctions. The assessment and improvement of vehicle delay models at signalized crossings is a major emphasis of the Highway Capacity handbook (HCM), the most referred to handbook for construction of highways. Due to pedestrian crossing behavior and mixed traffic circumstances, estimating pedestrian delay at a signalized crossroads is more difficult. Therefore, pedestrian delay is the most important KPI for measuring the LOS provided to pedestrians at signalized intersections.

Models and methods for estimating pedestrian delays are commonly derived from HCM, which is itself based on cycle length and the duration of the red phase, and which makes a number of assumptions, including a constant pedestrian arrival

Rate and non-compliant pedestrian flow, as well as a fixed cycle length and pedestrians who obey the basic rules without breaking them. Due to the model's assumptions, it is inefficient to predict pedestrian delay in mixed traffic situations, as is the case in India. In most areas, crossing the street during the solid red or flashing red phases is illegal for pedestrians. However, in India, pedestrians try to enter the crosswalk during non-green phases of the pedestrian signal system due to the wide variations in traffic conditions and the complexity of the pedestrian signal system. Those who breach the regulations of pedestrians are regarded to be violators based on a critical acceptable gap level (Critical acceptable distances are lower with faster walking speeds). The most common causes of pedestrian violations include poor traffic management, the absence of a designated pedestrian manager, a general lack of knowledge about traffic safety, and a high cycle time (more than 100 seconds). The value of pedestrian walking speed estimated at 1.2 m/s is a major concern for all current models, including the Indian Road Congress (IRC). In India's congested urban areas, a constant figure like this one for pedestrian walking pace is just not practical.

There hasn't been a lot of study done recently on the topic of pedestrian delay caused by vehicle-pedestrian contact at crosswalks. Models now in use are likewise restricted to the realm of pedestrian protection. If there is a safe window of opportunity and no one is monitoring the signalized crossroads, people will attempt to cross from the side streets to the median or refuge islands. Offenders wait for the next safe opportunity to cross to the other side of the road. Those who disobey the law in the median or crosswalk risk being stuck in traffic as a result of moving vehicles. Inconsistent drivers that ignore traffic signals and enter the crossing during the green light phase are a major cause of delays for walkers, as are cars blocking all or part of the crosswalks. The delay that pedestrians experience as a result of vehicle engagement at a crossing during green phases is often disregarded by current delay models. This research proposes a novel pedestrian delay model at signalized junctions that takes into account the aforementioned traffic circumstances and pedestrian behavior common in India's emerging cities. Finally, some final thoughts and suggestions for follow-up research are offered.

2. Literature Review:

In recent years, researchers have focused heavily on pedestrian delay models for rich nations, but little work has been done on pedestrian delay models based on traffic conditions and pedestrian behavior in developing countries. In 2013, researchers Lip vac et al. Reduce pedestrians' risk while crossing against traffic using the Countdown display at a signalized junction. The pedestrian features of Singapore's sidewalks and pathways were studied by Yordphol et al. (1986). Jodie et al. (2005) looked examined how people acted at signalized crosswalks, created a model for the correlation between pedestrian walking time and traffic flow, and tested it out. With and without the Light Rail Transit (LRT) train lines in the middle of the road, William et al. (2002) examined pedestrian flow characteristics at chosen signalized crosswalks in the Hong Kong metropolitan region. Using data on how people walk across cities, Teknomo (2002) created a miniature simulation model of pedestrian traffic. In 2012, researchers Nagaraj and Vedagiri looked at the correlation between pedestrian velocity, traffic volume, and density in India. The safety of pedestrians at signalized junctions in China was the topic of an analysis conducted by Gang et al. (2011). Using queuing theory, Zahir and Abaza (2007) modeled pedestrian crossing behavior, including speed and arrival pattern. At India, Kotkar et al. (2010) studied pedestrian traffic patterns at crosswalks with varying densities of motorized vehicles. Because pedestrian safety is such a pressing issue in China, Zhu et al. (2011) looked at the trends in lawbreaking and legal compliance. Pedestrians' actions at a red light were studied by Jing et al. (2011).

Using solely the arrival patterns of pedestrians, Kruszyna et al. (2006) suggested novel delay estimate models that vary in their degree of accuracy, complexity, and practical value. The maximum pedestrian crossing rate (MPCR) was used by Heungun et al. (2000) to create a pedestrian delay model. Using an automobile-pedestrian Monte Carlo model and a statistical model for estimating pedestrian delays at crossroads with pre timed two-phase control, Chen et al. (2010) aim to create a pedestrian delay estimation model for crossings in emerging cities. Vehicle delays at a green traffic light controlled by a pre-timed four-phase signal were estimated using a Monte Carlo model by Qingfeng et al. (2007). In this case, pedestrians who ignore the crosswalk lights are mostly to blame for the traffic backup. Some assumptions and a novel model based on average pedestrian delay and arrival sub-phases are derived from a Chinese field investigation (Qingfeng et al., 2005). In 2010, Xuan and Zong created a pedestrian delay model with a two-phase crossing layout. The Pedestrian delay models that take into account pedestrian crossing behavior and vehicle contact are called for in the literature. This research is an effort in that general field.

3. Study Location:

Population in India is 121 crores, making it one of the most populous countries in the world. The city of Mumbai serves as the state capital of Maharashtra in India. It has a metropolitan population of over 20.5 million people, making it the most populated city in India and the fourth most populous city in the world. The city of Mumbai is a perfect spot to work on the pedestrian delay model. The signalized intersections in Mumbai included in the research are all standard four-arm types, and their traffic light cycles are all predetermined. Figure 1 shows a sketch of the research areas chosen in Mumbai.

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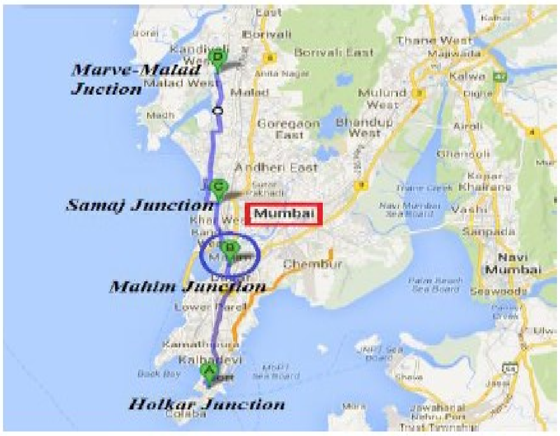


Location of the Study: a Developing City in India's Largest Metropolitan Area, Mumbai

Information gleaned from videotapes is summarized in Table 1. Video recording equipment was used to capture data at 1-hour intervals. Data on pedestrian traffic, crosswalk use, and more were all captured on camera. Length, crossing locations (crosswalk use), pedestrian phase times (green, flashing red, and red), crossing behaviours (walking, running, alone, and group crossings), pedestrian appearance character (gender, age group, and walking speed), and pedestrian-vehicle interaction.

Table 1: Measurements taken in the Field and Study Location

Site Identity	Intersection Name	Date of survey	Time of Survey	Length of Crosswalk (m)	Pedestrian Phase (Sec)		
					Green	Flashing Red	Red
A 2	Holkar Junction	05.04.13	5pm – 6pm	25	22	3	55
A 1		22.05.13	5pm – 6pm	31.5	25	3	121
B 1	Mahim Junction	22.05.13	9am-10am	20	35	2	106
B 2		22.05.13	9am-10am	13.5	19	3	121
C	Juhu-Linking Road Junction	07.06.13	9am-10am	19	12	3	118
D 1	Malad-Marve Road Junction	07.06.13	5pm – 6pm	33.1	52	3	195
D 2		07.06.13	5pm – 6pm	23	46	3	201

4. Pedestrian Behavior Analysis

Previous research has focused mostly on pedestrian traffic patterns and the amount of time spent on footpaths and walkways. Only a small number of studies have examined pedestrian behavior at signalized junctions, and those that have done so have mostly concentrated on generating and analyzing data for pedestrian crossings during red lights. Periods when the pace of walking changes. However, in developing nations like India, there is currently no pedestrian delay model that has been constructed purely on the basis of all probable pedestrian crossing behaviours at signalized junctions. This work makes an effort to construct a comprehensive model by analyzing pedestrian crossing behaviours such as walking speed, potentially volatile pedestrian behaviours, and Pedestrian-vehicle interaction on crossings using acquired field data in Mumbai.

4.1. Walking Speed

Table 2 with necessary classifications such as pedestrian gender, age group, platoon effect and traffic signal In India, the present design practice in signalized intersections is to assume the pedestrian walking speed to be a constant value of 1.2m/sec. From field study conducted in Mumbai, the crossing behavior of pedestrians has been found to be largely varying from the assumed constant value. The major reasons for walking speed variation have been found to be of the following: (i) Very less pedestrian green phase, (ii) Violating behavior of

Pedestrians, (iii) Platoon effect and (IV) Directional crossing effect so during design of signalized intersections in developing countries like India, there arises a need to consider all possible pedestrian crossing behavior and other influence factors. According to the analyzed field data from five crosswalks at signalized intersections in Mumbai under mixed traffic conditions, the calculated pedestrian walking speed are tabulated in. From the field data, the crossing speed variations of pedestrian analyzed and results are tabulated in Table 2.

Table 2. Pedestrian walking speed based on pedestrian and traffic characteristics at selected intersection crosswalk in Mumbai

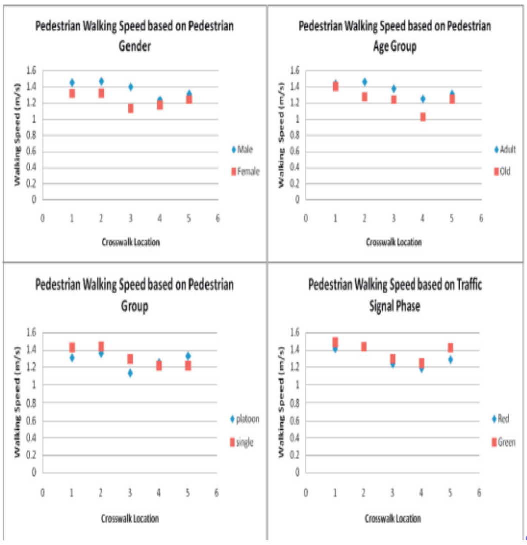


Figure 2: The relationship between pedestrian and traffic parameters at a crosswalk at a specific Mumbai crossroads.

The following conclusions were drawn from a comparison of pedestrian walking speeds depending on pedestrian characteristics, as shown in Figure 2. Men walk faster than women on average, at 1.37 meters per second compared to 1.26 meters per second. The average walking pace of a pedestrian over the age of 60 is 1.23 meters per second, whereas the average walking speed of a pedestrian aged 21-60 is 1.36 meters per second.

Because there is so little pedestrian green time in India, people walk faster during the green phase (1.35 m/s) than they do during the red phase (1.32 m/s).

Table 3: A Global Comparison of Walking Speed

Location	US	Malaysia	China	Hong Kong	London	India
Author	Tim J	Khalidur	Carbin	William	Muhammad	Present Field study
Pedestrian walking speed (m/s)	1.21	1.15	1.11 to 1.47	1.45	1.8	1.34

For the purpose of developing delay estimation models to determine crossing time delay at signalized crossings in India under mixed traffic situations, it is recommended that the above determined walking speed be used as a constant value.

4.2 Pedestrian Violation behavior

According to data gathered in the field, out of 1565 pedestrians, 942 committed the illegal act of crossing the street during the forbidden "red light" period. The data shows that in Mumbai, 60.19% of pedestrians follow the rules of the road. According to Table 4, violation rate as a % of total crosswalk data.

Crosswalk speeds and percentages of violators in Mumbai are shown in Table 4.

Site Identity	Crosswalk length (m)	N (Sample)	Mean Walking speed	Std Deviation	% of Violator
A 2	25	54	1.4229	0.27101	65.06
A 1	31.5	337	1.4394	0.32091	65.28
B 1	20	402	1.2942	0.34111	43.89
B 2	13.5	272	1.2150	0.2295	56.62
C	19	143	1.2150	0.2295	89.87
D 1	33.1	13	1.5304	0.38084	65.41
D 2	23	20	1.2942	0.17953	64.85

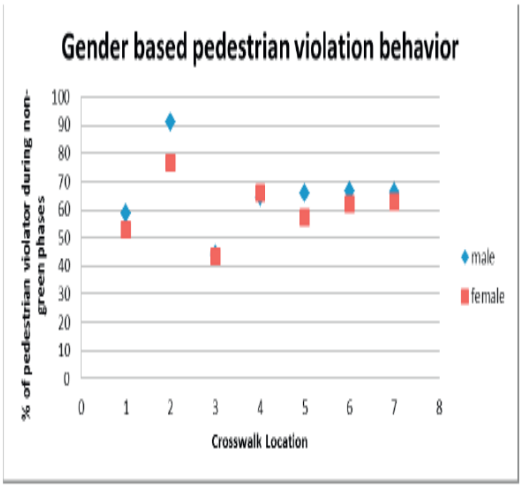


Figure 3: Gender and age differences in crossing violations at a signalized junction

Male offenders make for 65.27 percent of the total, while female offenders account for 60.14 percent, as seen in Figure 3. The primary cause is that male pedestrians are more likely to accept tiny gaps, hurry up their walking, and cross the street. In the middle of a red light crossing. So, obviously, the reason pedestrians disobey the signal is to save time. Vehicle-on-crosswalk interactions and far-side vehicle movement have also been linked to delays for offenders. Estimating pedestrian delays at signalized junctions is advised taking into account that pedestrians use up to 60% of the red phase duration. It is recommended that other factors, such as pedestrian-vehicle contact, the platoon effect, and the orientation impact, be included into the delay model.

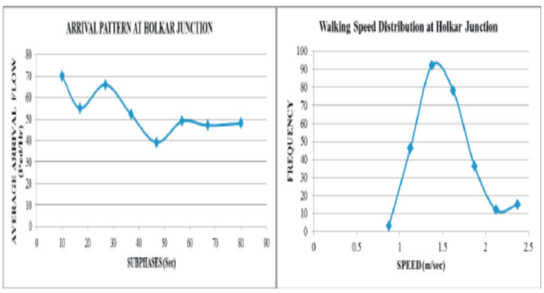
5. Model Development:

Data from Holkar Junction in Mumbai is shown in Figure 4. As can be seen in Figure 5, it was decided to create a pedestrian delay model for the crossing on the western leg (A1) of the junction.

Photos 4 and 5. Holkar Junction and a crosswalk (A1) on its western leg were chosen as the study site.*5.1.*

Pedestrian Behavior Analysis at Holkar Junction:

Out of the five intersections where pedestrian delay data was collected in depth, Holkar junction in Mumbai has been chosen for model development. The following parameters have been determined thanks to data taken from the one-hour video survey: Distribution of foot traffic, Normal pace, Lawbreakers, additionally Pedestrian-automobile dialogue. Every 10 seconds constitutes a new phase in the cycle's 80-second duration. Figure 6 depicts the non-uniform arrival behavior of pedestrians at the Holkar signalized crossroads in Mumbai during peak hours when traffic is heavy. The distribution of pedestrian speeds at Holkar intersection is shown in Figure 7; the curve fits a normal distribution. The average speed of a pedestrian is 1.4 m/s, while the percentage of people who break the law is 65%.



Figures 6 and 7 shows the distribution of pedestrian speeds at Holkar intersection and the arrival pattern of pedestrians in each sub phase.

5.2. Pedestrian delay model development

There are three parts to the new model that we've built. First, we use an HCM model to calculate the typical delay in waiting times. For the second part, we choose a value of 1.34 m/s (derived from actual field data) for both the crossing wait time and the pedestrian walking speed. The third factor is the time it takes for pedestrians and drivers to engage. Here is the updated model that is being proposed:

$$D_{Avg} = D_{WT}+D_{CT}+D_{VIT} \quad (1)$$

Where DWT = avg. wait time per pedestrian during non-green phases, DCT = avg. cross time per pedestrian during all phases, and DVIT = avg. veh. Pedestrian inters. Time per pedestrian during all phases.

5.2.1 Waiting Time Delay:

$$D_{WT} = \alpha_1(C-(G+\alpha_2 R))^2/2C \quad (2)$$

$$\alpha_1 = (C/R)/(n_T/n_R)$$

Data from the field showed that 60% of pedestrians were lawbreakers, and the uniform arrival pattern adjustment factor is 0.81 (equation 3). The new model estimates a delay of 7.18 seconds due to waiting.

5.2.2 Crossing Time Delay

$$D_{CT} = \text{Actual Crossing Time} - \text{Ideal Crossing Time} \quad (4)$$

The optimal crossing time is the ratio of crosswalk length to pedestrian walking pace, and this was derived from field data. Table 3's value for pedestrian walking speed was used, and the delay time for crossing at Holkar intersection was calculated to be 0.8 seconds.

5.2.3 Vehicular Interaction Delay

The length of time it takes for pedestrians and cars to interact at a crosswalk depends on many variables, including the number of people and cars using the crossing, the direction in which they are moving, and the time gap between when they both arrive. The average pedestrian gap acceptance time is 4.5 seconds at the Holkar intersection crossing (A1), with a minimum gap acceptance time of 1.6 seconds. On crosswalk A1, the volume of entering vehicles is 2518pcu/hr and the volume of leaving vehicles is 2670pcu/hr. Pedestrian traffic is lower in the U2D direction (164 ped/hr) than in the D2U direction (173 ped/hr).m At Holkar intersection, the delay between pedestrians and drivers interacting between pedestrian green and red phases was measured to be 11.78 seconds. Using equation (1), we can calculate that the average wait time for pedestrians at Holkar intersection is 19.7 seconds.

6. Comparisons with existing pedestrian delay models:

At signalized intersections, the most popular pedestrian delay model is as follows,

$$D = (C-G)^2/2C \quad (5)$$

D represents the typical wait time of pedestrians, C the duration of a complete cycle, and G the amount of time a light is green. The presented model assumes a constant cycle length, pedestrian compliance with traffic signal laws (HCM), and a uniform pedestrian arrival rate. The following model was established by Braun and Roddin (1978) after they took into account the fact that some pedestrians disobey traffic lights.

$$D = F(C-G)^2/2C \quad (6)$$

Where F is the percentage of pedestrians that enter the crosswalk during a non-green phase and wait for the light to change. According to the formula, pedestrians who disobey traffic signals will experience no additional delays. A model based on pedestrian infractions during clearing time was created by Virkler (1998).

Follows,

$$D = (C-(G+0.69A))^2/2C \quad (7)$$

And let's call it Clearance Time, A. In China, Qingfeng et al. (2005) created a pedestrian delay model based on non-uniform traffic conditions. Pedestrian arrival times and wait times at green lights

$$D = d_G + (K_{NU} * K * R^2)/2C \quad (8)$$

Where dG is the median arrival time lag of pedestrians coming during green phases, KNU is the non-uniform arrival rate adjustment factor, k is the absolute value of the descending line, and R is the effective red duration.

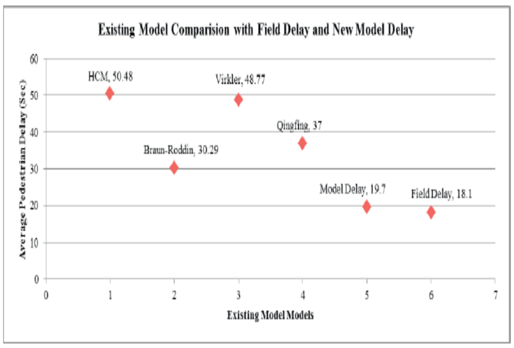


Figure 8. Existing Model Comparisons with Field Delay and New Model Delay at Holkar junction

$$\text{Field Delay} = ((\text{Finishing time} - \text{Arrival time}) - \text{Field crossing time})/\text{Number of arrival pedestrian} \quad (9)$$

In Figure 8 we see how the field delay stacks up against previously proposed models. Most current models overestimate the delay time in the field, and it is discovered that none of the available models can predict the delay time properly. Along with this, a novel pedestrian delay model was introduced in this work, which provided an estimate of near-field delay. Moreover, the proportion the new model has a delay that is 8.12% longer than the field delay. Because of this, the new model may be used in cities with a wide variety of traffic types, such as those seen in India.

7. Conclusions

This article demonstrates that current methods for estimating pedestrian delays at signalized junction crosswalks are inadequate. The models' inaccuracy is mostly attributable to the assumptions that prevent the consideration of all conceivable pedestrian crossing scenarios. Activities at signalized junctions with heavy pedestrian and vehicle traffic in emerging markets like India. As a result, the current models are very specific and can only be used for certain kinds of signalized junction crosswalks. Because it takes into account every potential pedestrian crossing behavior in Mumbai, the novel technique described in this research for delay estimate model creation is applicable when the old models have failed to anticipate properly. To refine the model's predictions, further study of pedestrian-vehicular interaction delays is required.

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