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Case Study of Pedestrian Risk Behavior and Survival Analysis

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ABSTRACT

In order to improve traffic flow, signal-free, grade-separated intersections in Delhi have often replaced signalized intersections. Evaluating the impact of signal free intersections on pedestrians is important when nearly fifty percent fatalities in the city involve pedestrians. Examining a pedestrian sample before and after site reconstruction produces a better understanding of the subsequent changes in pedestrian risk behavior.

Strategically placed camcorders viewed pedestrians and approaching traffic. Data reduction measured the accepted time gap of each pedestrian making an unsafe crossing and the average speeds of the approaching vehicle groups. A pedestrian survey provided additional information. Sixty two percent pedestrian accepted gap less than 4 seconds(exposed to high risk) after site reconstruction compared to fifteen percent pedestrian accepting similar gap before the site reconstruction. More than 35 percent of pedestrian stage crossings had accepted gaps less than one second as compared to 6 percent of pedestrian stage crossings before reconstruction. After reconstruction, 22% of pedestrians did not use the pedestrian underpass and continued unsafe crossings at the site.

Pedestrian exposure to greater risks of bodily injury and death with site reconstruction occurred despite the presence of an underpass and median barrier. Pedestrians had exposure to higher risks after the construction of the signal-free crossing. Not all pedestrians used the pedestrian subway. The design and location of the pedestrian subway needs modification.

keywords: pedestrians, behavior, signal-free intersection, risk,

1. INTRODUCTION

In Delhi, the government has made significant investments for the construction of flyovers, i.e., grade-separated intersections, to increase speeds of motorized vehicles, to reduce vehicular delays, and to make signal-free, arterial roads in Delhi. With the construction of flyovers, pedestrian-crossing problems arise. To solve these problems, the construction of many pedestrian subways, i.e., underpasses and foot over-bridges, i.e., overpasses has occurred. However, the usage and effectiveness of pedestrian subways and foot over-bridges is poor. Understanding the problems that pedestrians face and why pedestrians are reluctant to use subways and foot over-bridges would ultimately improve the usage and effectiveness of these pedestrian facilities.

Several researchers have studied pedestrian behavior at signalized and unsignalized crossings. Hamed (2000) studied the factors that influence a pedestrian's waiting time and frequency of attempts to cross streets. He found that pedestrians' expected waiting time has profound influence on the number of attempts needed to successfully cross the street. Hamed established that pedestrians who spend more time waiting to cross from one side of the street to the median are likely to have a higher risk of ending the waiting time than when they cross from central refuge to the other side of the street. Forsythe and Berger (1973) presented the results of interviews with pedestrians crossing at unsafe DON'T WALK signal indications or pedestrian red intervals. They reported that the reason for unsafe pedestrian crossings was mainly time-related. A need to hurry or a desire to keep moving was the main reason behind the lack of compliance with pedestrian signals. Tanaboriboon and Jing (1994) reported pedestrian attitudes in Beijing, China, towards the sufficiency of crossing facilities and the willingness of pedestrians to use them. The study compared signalized intersection pedestrian crossings to overpass and underpass counterparts and concluded that users preferred the signalized crossings to the overpass or underpass crossings. The authors also reported that the pedestrian crossing compliances with pedestrian signals at two study locations were 70% and 57%.

Rouphail (1984) performed user compliance and preference study on marked midblock crosswalks in downtown Columbus, Ohio. He found that users perceived the unsignalized marked midblock crosswalk to be unsafe. However, the same crosswalks were rated highest with respect to crossing convenience. Lassarre, Papadimitriou, Golias and Yannis (2005) defined an exposure indicator based on motorized vehicle concentration by lane which takes into account the speed of the traffic flow and the time spent to cross in two specific micro-environments: mid-blocks and junctions. They also developed a model of crossings by trip given the origin and destination based on the shortest path and a hierarchical choice model between mid-block and junctions according to the traffic characteristics and pedestrian facilities. Das, Manski and Manuszak (2003) examined the behavior of pedestrians wishing to cross a stream of traffic at signalized intersections. They modeled each pedestrian as making a discrete crossing choice by comparing the gaps between vehicles in traffic to an individual-specific "critical gap" that characterizes the individual's minimal acceptable gap. They proposed both parametric and non-parametric approaches to estimate the distribution of critical gaps in pedestrians. Tiwari, Bangdiwala, Gaurav, and Saraswat (2006) analyzed pedestrian crossing behavior using survival analysis. The analysis produced Kaplan-Meier survival curves for waiting time prior to crossing unsafely, separately for males and females. They found that as signal waiting time increases, pedestrians get impatient and violate traffic signal indications which placed them at increased risk of being struck by a motor vehicle. The All India Institute of Medical Sciences (AIIMS) signalized intersection where the authors studied pedestrian crossing behavior has become an unsignalized intersection. A comparison between the pedestrian crossing behavior after reconstruction into an unsignalized intersection and before site reconstruction revealed interesting conclusions.

A. Site Description

The AIIMS flyover interchange in New Delhi carries large flows of bus, pedestrian, and motor traffic. The Ring Road, which is a major arterial road, and Aurobindo Marg forms the AIIMS grade-separated interchange. Traffic data collection allowed the study of road user behavior earlier when the AIIMS junction was an at-grade, signalized intersection and presently when the site is a flyover interchange with no traffic signal control. Analysis produced results pertaining to pedestrian crossing behavior as a function of observable pedestrian, environment, and traffic characteristics.

Figure 1. shows a diagram of the site design when pedestrians crossed at a signalized intersection. Figure 2. shows the pedestrian crossing after site reconstruction. Arrows show traffic flow directions. In Figure 1., the camera placement viewed the zebra crosswalk of the southern arm. The northbound approach width that pedestrians traverse was 14.51 m, and the southbound egress width was 13.41 m. In the case after reconstruction into a flyover interchange, one camera is placed near AIIMS Main Gate and the other is placed near Safdarjung Hospital such that it views the pedestrians crossing Aurobindo Marg as shown in Figure 2 **Error! Reference source not found.**. The pedestrian crossing distance at 90 degrees to the northbound traffic is 22.25 m. The crossing distance involving the southbound traffic is 19.8 m. The distance from the western side of Aurobindo Marg's crossing to the pedestrian underpass is 55 m. From the underpass to the pedestrian crossing on the western side, the distance is 46 m .

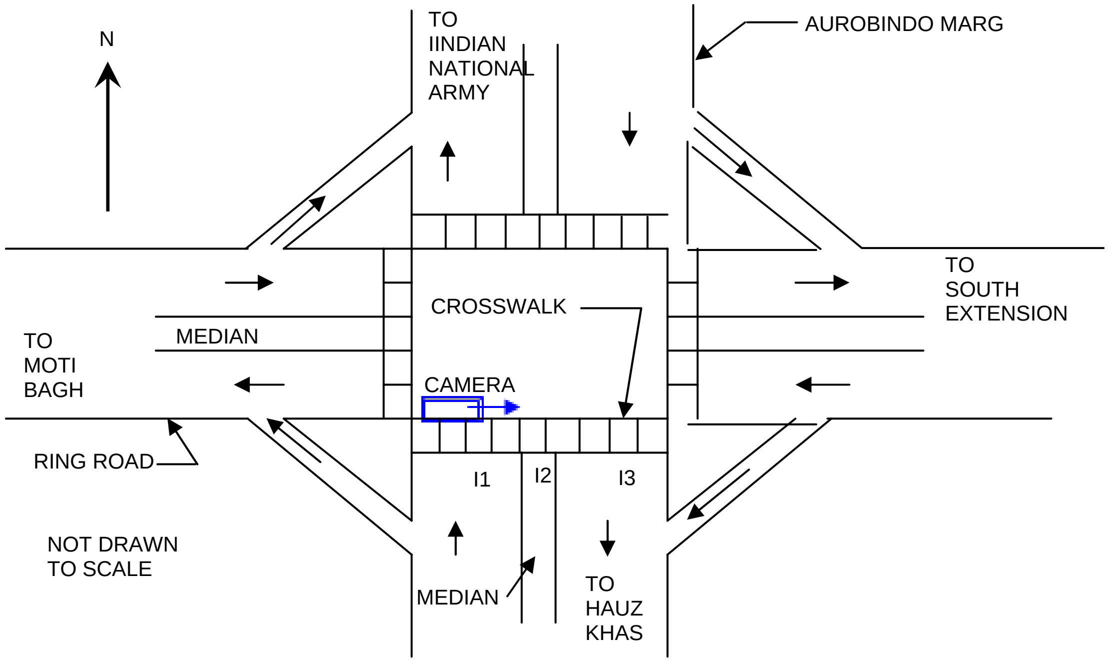

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Figure 1. Pedestrian Crossing Site before Reconstruction

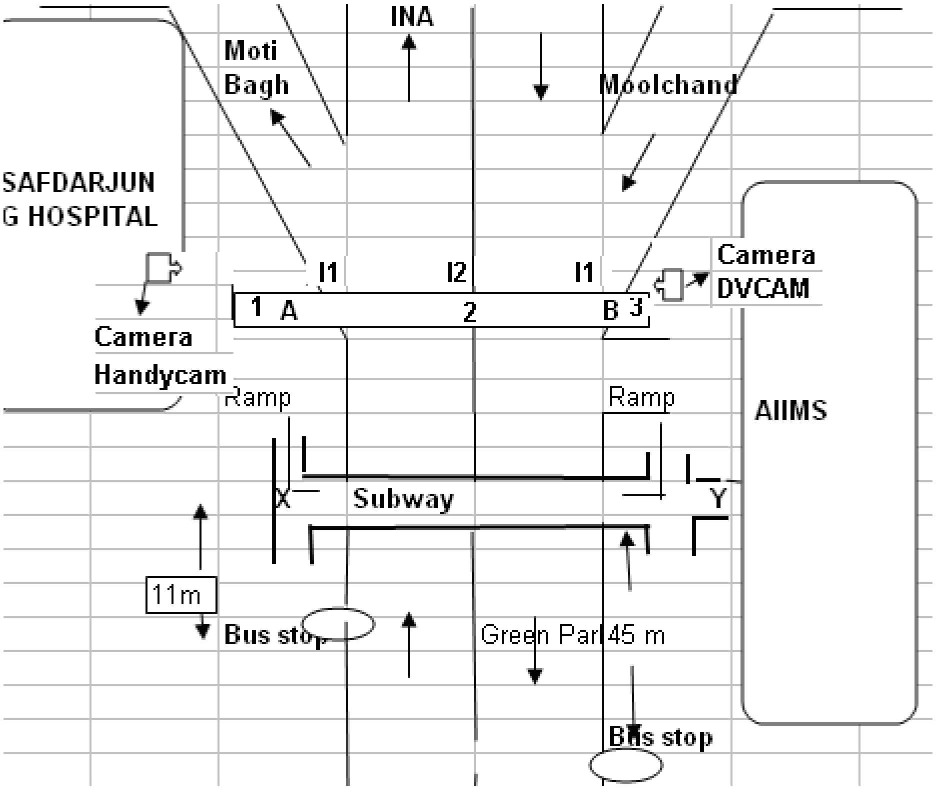

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Figure 2. Pedestrian Crossing Site after Reconstruction

The subway or pedestrian underpass at the Safdarjung Hospital side has ramped entrances from two sides. The underpass at the AIIMS side has ramped entrances from three sides. One entrance directly connects with the AIIMS Campus. The distance of the bus stop from the underpass at the Safdarjung Hospital side is 11 m and at the AIIMS side is 45 m .Also at the reconstructed site, the median railing barriers had several 'unofficial' openings or gaps. These openings allowed people to cross unprotected. In addition, some people jump over the railings to cross the road. The median railing barrier near the bus stand at the AIIMS side had an opening. Many bus users who desired to cross the road from the AIIMS side crossed the road unprotected at grade.

Pedestrians crossing the road at AIIMS after reconstruction

B. Description of Risk

The traffic signal's GREEN or WALK indication initially facing a pedestrian provides a protected or relatively safe pedestrian crossing because no interference or conflicts from vehicles should occur during such indications. When the indication is RED or DON'T WALK, the traffic signal provides an unprotected or hazardous crossing. When a pedestrian crosses the road during an unprotected interval,the pedestrian experiences a risk during the crossing. In some cases, one observes the same pedestrian experiences two risks in a two-staged, unprotected interval, e.g., one risk on arrival at the intersection and the other when crossing from the median. In other cases, one observes pedestrian crossing at risk during one stage and no risk during the next crossing stage. In some cases, pedestrians had only one decision point for the entire crossing.

Risk is a function of the time interval between the time when the conflicting vehicle reaches the pedestrian line of movement and the time at which pedestrian reaches the intermediate point i.e., the exposure time in which the pedestrian incurs a potential hazard with the approaching vehicle. This time interval is the pedestrian's accepted gap and denoted by T. When the accepted gap increases, risk decreases, i.e., $Risk = f(1/T)$. When the accepted gap is zero, risk is one, i.e. the vehicle strikes the pedestrian.

A critical time interval or critical accepted gap exists, T_{cr}, after which the risk faced by a pedestrian approaches zero, i.e., the slope of curve in Figure 3**Error! Reference source not found.** approaches zero. The expected shape of curve follows the same shape as the cumulative percent of pedestrian not crossing during RED versus the waiting time during RED.

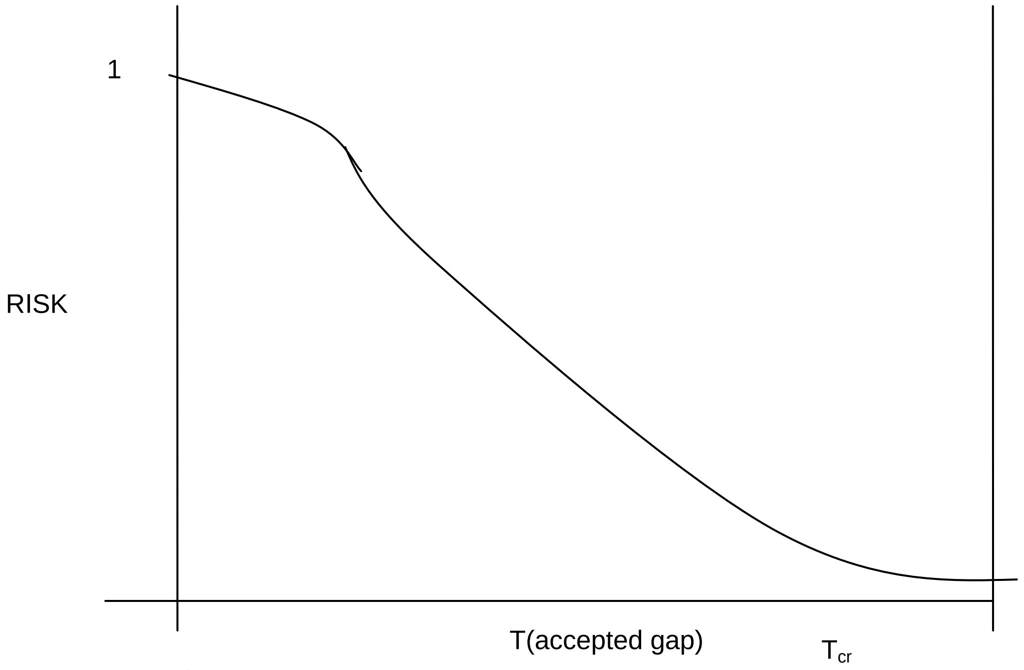

Figure 3. Risk Function

The analyses focused on pedestrians who cross at an unprotected traffic signal indication or cross when the traffic signal does not control motor traffic. When the site was a signalized intersection, the full pedestrian crossing had three intermediate points I1, I2, and I3 and a point on each sidewalk i.e., origin and destination as shown in Figure 1. I1 is the midpoint between sidewalk and median, I2and I3 are the midpoint between median and the other sidewalk. Pedestrians cross between these points in a stage. Four stages comprise a full pedestrian crossing, i.e., from sidewalk to sidewalk. Risk faced by a pedestrian in a stage is stage risk. When the approaching vehicle passes in front of the crossing pedestrian, the vehicle received an 'F' code. When the approaching vehicle passes behind the crossing pedestrian, it received a 'B' code. Using the arrival time of Vehicle B estimates the accepted gap of the pedestrian. The time taken for the front bumper of the nearest Vehicle B to reach the reference line, which is usually same as the pedestrian line of crossing, defines the accepted gap. In some cases, the front bumper almost reaches the pedestrian crossing line. When the AIIMS site became an unsignalized, flyover interchange after reconstruction, a traffic signal did not control motor traffic at the makeshift pedestrian crossing.

2. METHOD

The main objective is to compare changes in unprotected pedestrian risk-taking behavior at the same site when the site had interrupted flow and when it had uninterrupted flow. To reach the main objective, two sub-objectives precede. One sub-objective is to estimate the risk faced by unprotected pedestrians while crossing the road at a signalized junction. The second sub-objective is to estimate change in risk faced by pedestrians after the reconstruction of the site into a flyover interchange.

A. Data Collection

Data collection occurred at the southern zebra crossing of the AIIMS intersection before the reconstruction into a flyover by placing a video camera. A review of the videotapes allowed the study of pedestrian crossing behavior. Data collection used a high-quality Umatic digital camera equipped with a frame-by-frame timer. One second was equal to 25 frames. This time lapse allowed the obtainment of vehicle and pedestrian information at each instant.

After reconstruction of the site, two cameras collected relevant pedestrian traffic crossing Aurobindo Marg at-grade just south of the interchange ramps and approaching vehicular traffic as shown in Figure 2. The second Umatic digital camera with 25 frames per second collected additional data. A pedestrian survey collected data on the number of people using the pedestrian underpass to cross the road. Four persons conducted the survey. Two persons noted the details of the pedestrians crossing the road by the surface, one on the western side of Aurobindo Marg and the other on the eastern side. Both were just south of the interchange ramps. The third observer noted the details of the pedestrians at the AIIMS exit, and the fourth person noted the details of the pedestrians at the Safdarjung exit of the underpass.

B. Data Processing

Coding of the data occurred in the laboratory of the Transportation Research and Injury Prevention Program (TRIPP) at the Indian Institute of Technology Delhi. Progressing the videotape one frame at a time allowed the viewing of pedestrians and vehicles. A 74 cm (29 in) monitor displayed the frames, and two research assistants together coded the data. Moreover, viewing the tape many times allowed the coding of all relevant information for pedestrians and vehicles and error checking and correcting.

Two sets of variables tagged each pedestrian. The first set describes the pedestrian's attributes and movements. The coded attributes include gender, age group, and situation, i.e., with or without heavy baggage, with or without children, and handicapped. The movement information includes the direction of the crossing, the time of arrival at the intersection, the time the crossing begins, the times of arrival at and departure from the median, and the time of crossing completion. The completion time is only for the case before reconstruction. Due to the presence of median railing barriers after reconstruction, observations of full crossings by pedestrians from a single camera could not be made, only half crossings. A full crossing occurred when the camera viewed a crossing pedestrian for the full width of the arm or street. When the camera viewed a crossing pedestrian for only the half width of the arm or street, a half crossing occurred. This variable set included the status of the traffic signal indication for the case before reconstruction.

The second set of variables describes the flow of potentially conflicting vehicles during the period that a pedestrian waits and crosses. For each vehicle, the pedestrian location during the period of potential conflict, i.e., origin sidewalk, near road lane, median, far road lane, or destination sidewalk, the vehicle position relative to the pedestrian, i.e., whether it passes in front of or behind the pedestrian, and vehicle type were variables. This variable set also contained the direction of travel, lane of travel, and the precise period during which the vehicle physically conflicts with a crossing pedestrian. This period includes the time when front bumper of the vehicle crosses the reference line, i.e., the begin time. End time is when the rear bumper touches the reference line. Begin time and end time are used to compute speed of the vehicles using the length of each type of vehicle. Doing this is important because the reference line is mostly but not always where the pedestrian is. One may assume that the vehicle speed is the same at the reference line and at the pedestrian position. When a vehicle's begin and end times are not observable such as when pedestrians are crossing from west to east and a bus obstructs the camera's view, these times are set to zero.

C. Survival Analysis

One uses survival analysis because the interest is the time to the event occurrence of crossing unsafely, i.e., GREEN or YELLOW signal indication facing motor vehicle traffic. It occurs only once for a particular subject. For studying pedestrian crossing behavior, 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-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 definition of the Kaplan-Meier estimated survival curve is:

$$S_{KM}\left[t(i)\right] = \prod\nolimits_{j^*}\left\{1-d(j)/r(j)\right\} \tag{1}$$

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, i.e., those who have not yet crossed unsafely or those whose time to unsafe crossing is censored.

One can adjust the estimated K-M curve for the effects of covariates either by stratified analysis or by modeling. Mathematicians typically use the proportional hazards regression model of Cox (1972) to model survival times adjusting for multiple covariates. In the survival calculations, adjustment only for pedestrian gender occurred using stratified analysis. SYSTAT 8.0 performed all calculations.

D. 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 seconds, these pedestrians were assigned waiting times of 0.039 seconds. The pedestrian with the above coded wait time are said to have negligible wait time.

In the analysis involving the after reconstruction case, waiting times in the four stages are set as survival times. Some pedestrians do not wait before crossing, i.e., they arrive and cross with only a cursory non-measurable stop. In order to include them in the survival analysis and since the precision of the time measuring device was 0.04 seconds, these 'nonwaiting' pedestrians had 0.039 seconds as their waiting times. The censoring variable is a binary indicator variable. The variable received a '0' value when the censoring of waiting times occurred, i.e., pedestrians crossed protected. A value '1' occurred for waiting times when the pedestrians crossed unprotected. In the after reconstruction case, all waiting times received a '1' value since all pedestrians crossed the street in an unprotected manner.

3. RESULTS

Before reconstruction into a flyover interchange, the pedestrian study revealed 640 pedestrians used the southern crosswalk. From those, 400 pedestrians did safe crossings, and 240 did partially safe or full unsafe crossing. After reconstruction, 344 pedestrians made unsafe crossings. Table 1 shows pedestrian characteristics before and after reconstruction into a flyover interchange. Table 2presents the pedestrian survey results after reconstruction. The approaching speed characteristics of the conflicting vehicles appear inTable 3. Table 4 has the pedestrian waiting characteristics for each of the four crossing stages. Figure 4 shows survival analysis results. The four curves show the waiting time pattern of pedestrians in each crossing stage.

Table 1. Pedestrian Characteristics and Crossings

		BEFORE RECONSTRUCTION	AFTER RECONSTRUCTION
TOTAL PEDESTRIANS		640	344
GENDER			
	MALE	80%	74%
	FEMALE	20%	26%
AGE			
	CHILD	4%	2%
	YOUNG TO MIDDLE AGE	89%	91%
	OLD	7%	7%
FULL CROSSINGS		586	0
HALF CROSSINGS		54	344

Table 2. Pedestrian Survey Results after Reconstruction

DIRECTION	CROSSING TYPE	
	AT GRADE (UNPROTECTED)	PEDESTRIAN UNDERPASS (PROTECTED)
AIIMS TO SAFDARJUNG	399	638
SAFDARJUNG TO AIIMS	318	1878

Table 3. Speed Characteristics of Conflicting Vehicles

VEHICLE GROUP	BEFORE RECONSTRUCTION		AFTER RECONSTRUCTION	
	MEAN SPEED KM/H (MI/H)	STANDARD DEVIATION KM/H (MI/H)	MEAN SPEED KM/H (MI/H)	STANDARD DEVIATION KM/H (MI/H)
BUS/TRUCK	25.0 (15.5)	7.9 (4.9)	30.4 (18.9)	11.2 (7.0)
CAR	26.5 (16.5)	8.9 (5.5)	32.5 (20.2)	12.3 (7.6)
MOTORIZED THREE WHEELER	21.4 (13.3)	7.5 (4.7)	24.6 (15.3)	9.5 (5.9)
MOTORIZED TWO WHEELER	26.6 (16.5)	8.6 (5.3)	35.0 (21.7)	11.0 (6.8)

Tablele 4. Pedestrian Waiting Times

	CROSSING STAGE			
	1	2	3	4
MEAN, SECONDS	4.8	7.7	7.6	0.6
TIME WHEN 90% CROSSED, SECONDS	15.0	22.8	23.0	1.0
ZERO WAITING TIME, %	65	48	25	86

4. DISCUSSION

Most unprotected pedestrians who crossed the street at grade crossed in groups or platoons. Pedestrians crossing from the median formed the most platoons. In absolute terms, males outnumbered females by approximately 3:1. Approximately 90% of pedestrians belonged to the 'young to middle age' group

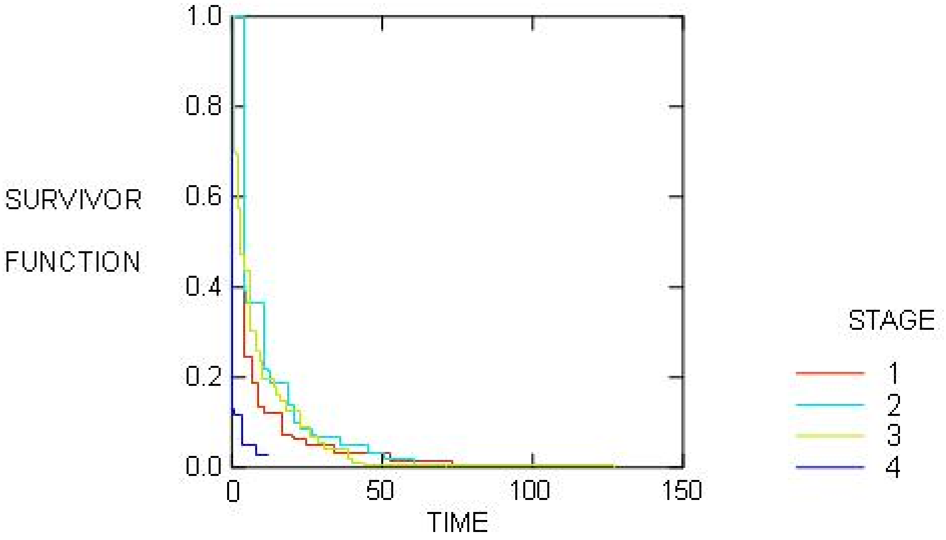

Figure 4. Survival Function for pedestrians at different stages of crossing

After reconstruction and despite a median railing barrier and a nearby pedestrian underpass to prevent crossing at the site, approximately 22% of 3233 pedestrians still used the site and are at risk with motor traffic. Approximately, 40 percent of the pedestrians crossed the street at grade from the AIIMS to Safdarjung Hospital direction while 15% of the pedestrians cross by the surface from Safdarjung Hospital to AIIMS direction. However, this percentage is actually more since the median railing barriers had openings in different places from where people cross and since some pedestrians easily jumped over them. Such events were outside the view of the four observers, and the observers could not count them. The observers did count pedestrians at one location where no median railing barriers were present. An underestimation occurred in the survey's pedestrian counts where pedestrians crossed at grade. Further, the bus stand location at the AIIMS side is 45 m to the underpass; most pedestrians chose to cross unprotected at grade.

The stationed observers at the underpass exits counted pedestrians as they exited the underpass. The pedestrian underpass had many medical and other shops. Some people went into the underpass to buy medicines or make other purchases when they exited again they were counted by the surveyors as people using the underpass for crossing. This event occurred largely on the AIIMS side since the hospital connects to the underpass and since many shops are near its exit. This double exiting phenomena lead to an overestimation of the people using subway to cross the road.

Figure 5 shows the percentage of all stage crossings versus accepted gap. When the accepted gap is more than four seconds, risk to the pedestrian becomes negligible. Figure 5 shows the percentage of stage crossings versus accepted gap before reconstruction. It includes all unprotected pedestrian crossings for all stages whether full or half. Only 15 percent of the stage crossings had a risk, i.e., accepted gaps less than or equal to four seconds. The remaining 85 percent had negligible risk. Figure 6 shows the percentage of stage crossings versus accepted gap after reconstruction. It includes all unprotected stage crossings that pedestrians completed. Only 38 percent had negligible risk. In **Error! Reference source not found.**, risk has increased after reconstruction; more than 35 percent of stage crossings had accepted gaps less than one second as compared to 6 percent of stage crossings before reconstruction.

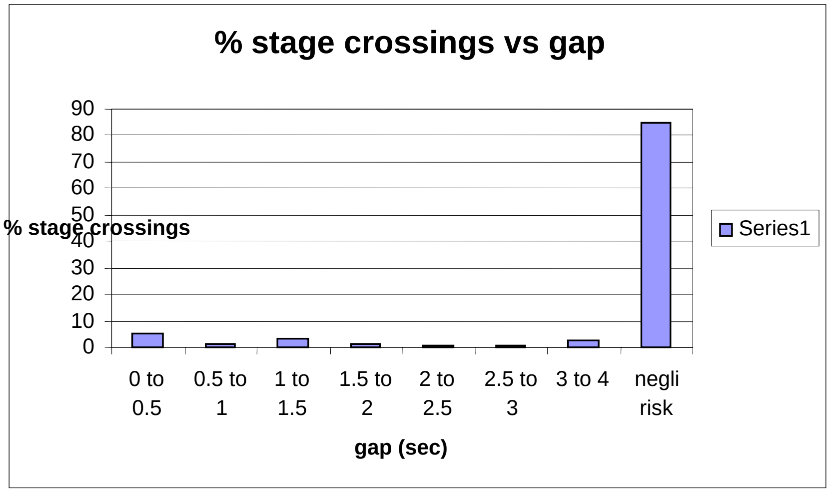

Figure 5 Accepted gaps before reconstruction

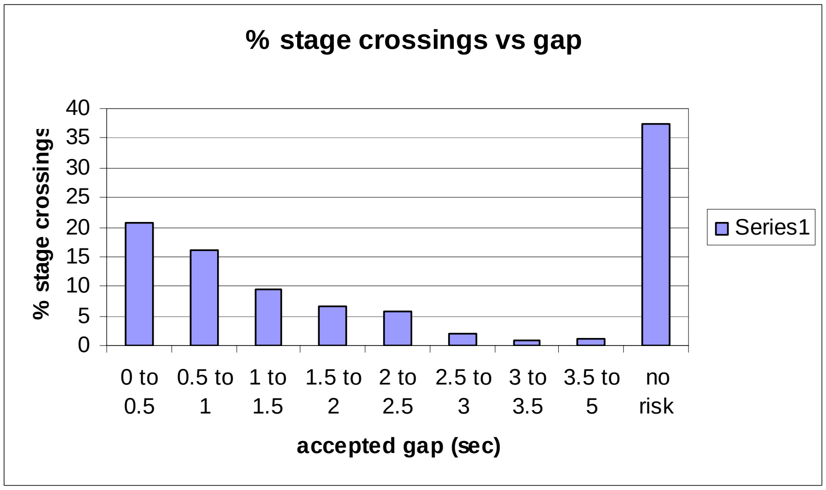

Figure 6. Accepted Gaps after Reconstruction

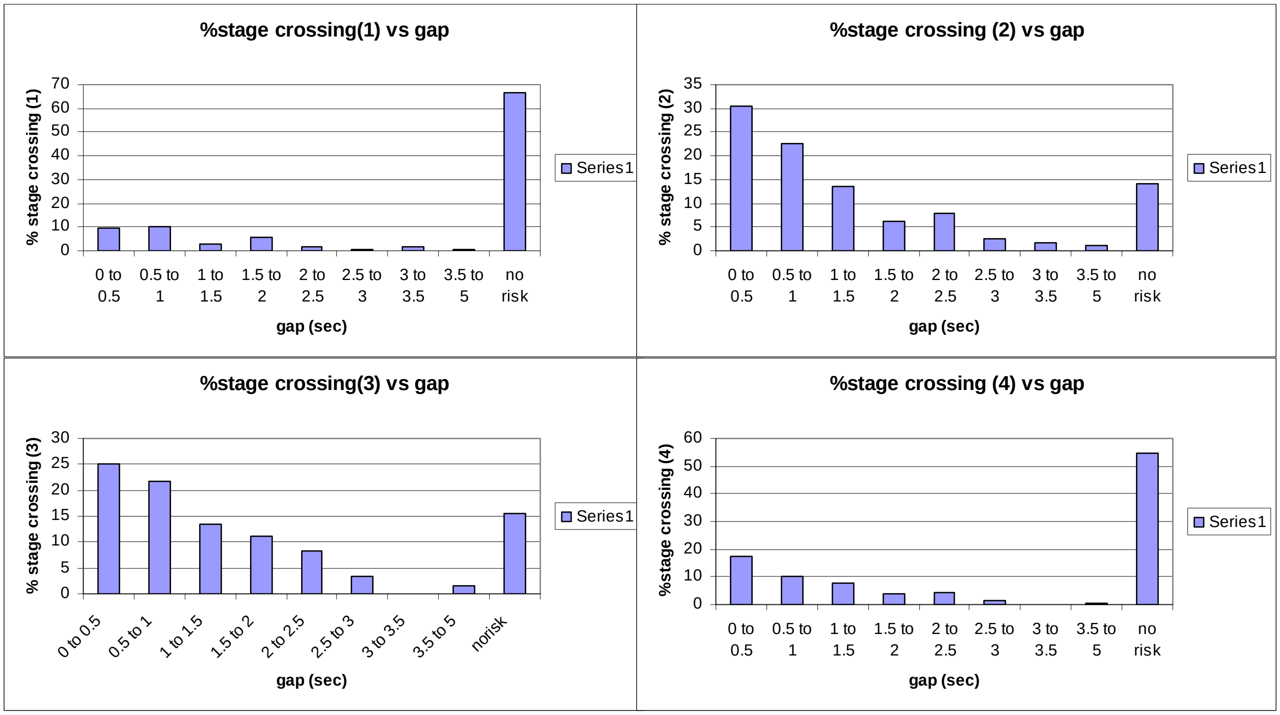

Figure 7. Accepted Gaps by Stage after Reconstruction

From Figure 7 we see a greater percentage of pedestrians had exposure to higher risk, i.e., accepted gaps less than one second while pedestrians are in Stage 2 and Stage 3 crossings than Stage 1 and

Stage 4 crossings. In Stage 1 and Stage 4, a very large number of pedestrians are facing negligible risk while this percentage is low in Stage 2 and Stage 3. Stage 2 and Stage 3 involve more approaching cars and other fast approaching motorized traffic.

Figure 8 shows , more than 50 percent of pedestrians walk in platoons after reconstruction while this percentage is 18% before reconstruction. This difference indicates that people feel more risk while crossing alone so they follow group behavior. Observers in the pedestrian survey saw that most pedestrian platoons forced vehicles to temporarily stop or significantly slow so that the pedestrians could cross the road.

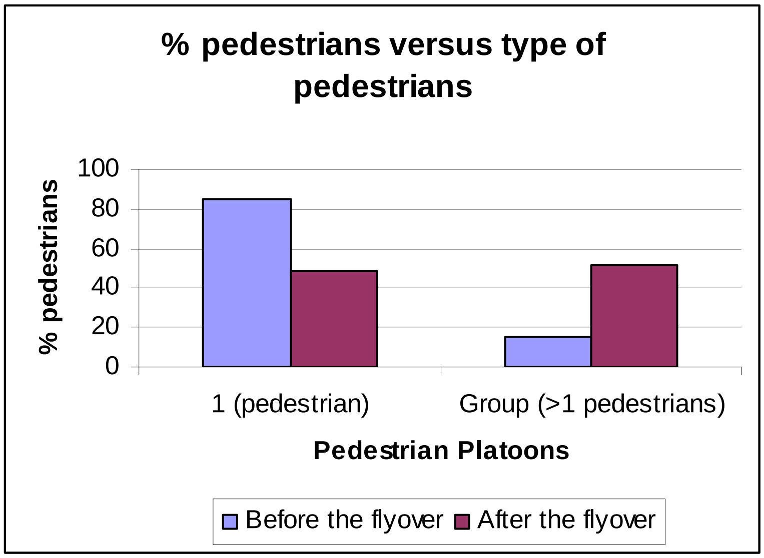

Figure 8. Pedestrian Platoon Phenomena

Previous research has shown that when the impact speed increases beyond 30 km/h, then pedestrian fatality risk steeply increases(Pasanen, 1991). Table 3 shows the average speed and standard deviation of all motorized vehicle groups. All have increased after reconstruction. This entails that risk to the pedestrian has greatly increased. For instance, when the average speed of the car group was 26.5 km/h (16.5 mi/h) before reconstruction, the probability of death was approximately six percent. After reconstruction, the average speed of the car group increased to 32.5 km/h (20.2 mi/h), the probability of death approximately doubled to 12 percent.

From **Error! Reference source not found.** through Figure 12, higher percentages of vehicles are traveling with higher speeds in all categories after reconstruction. Risk to pedestrians has increased because conflicting vehicle speeds after reconstruction are higher as compared to before reconstruction.

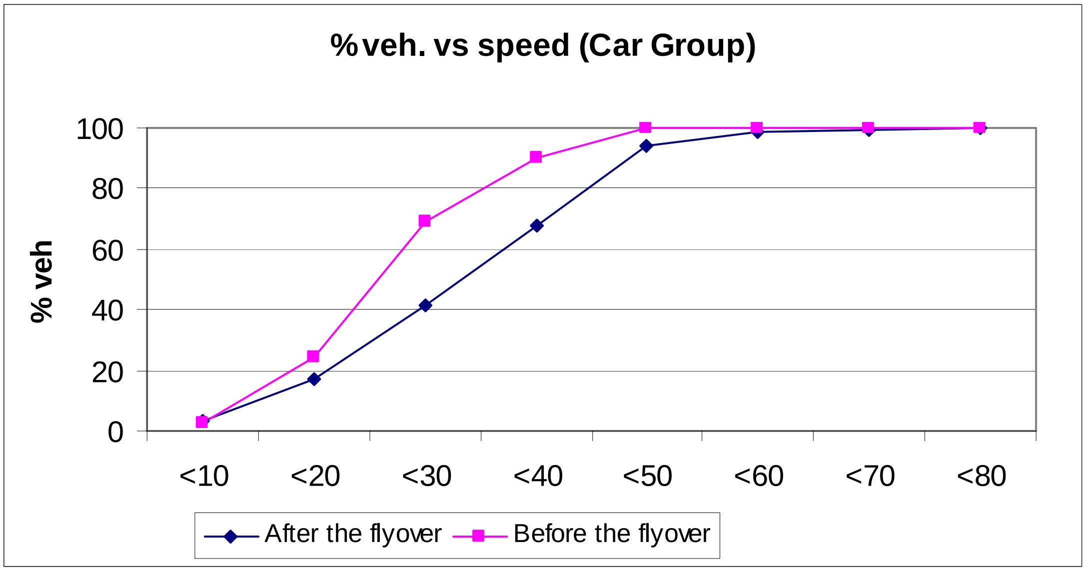

Figure 9 Speed Distribution of Car Group

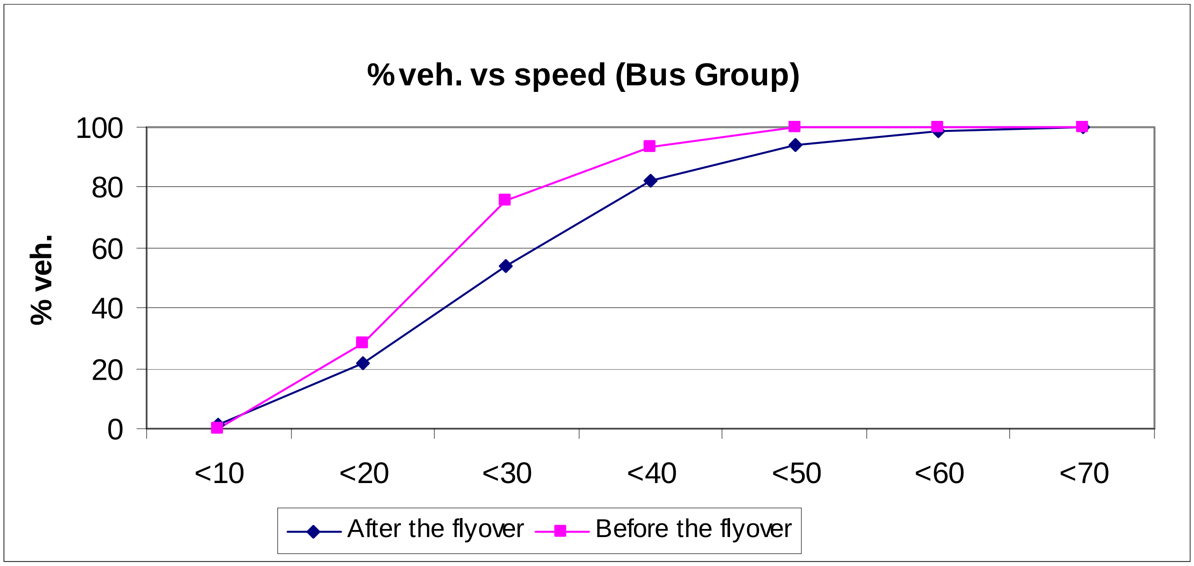

Figure 10. Speed Distribution of Bus Group

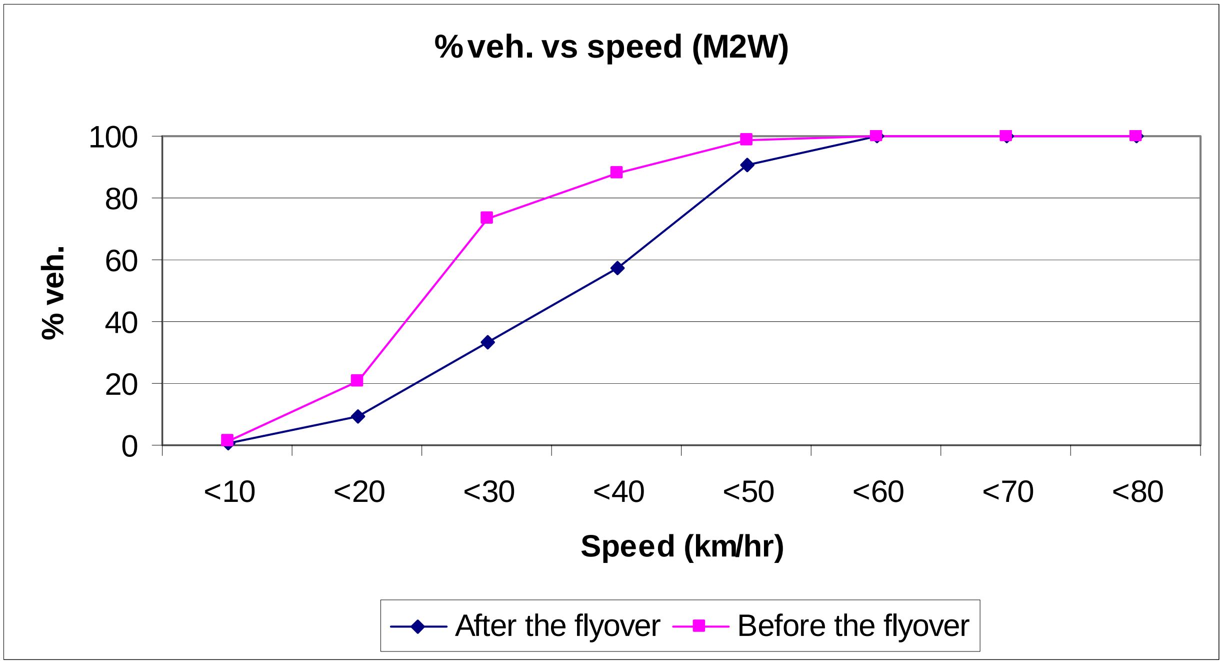

Figure 11. Speed Distribution of Motorized Two-Wheeler Group

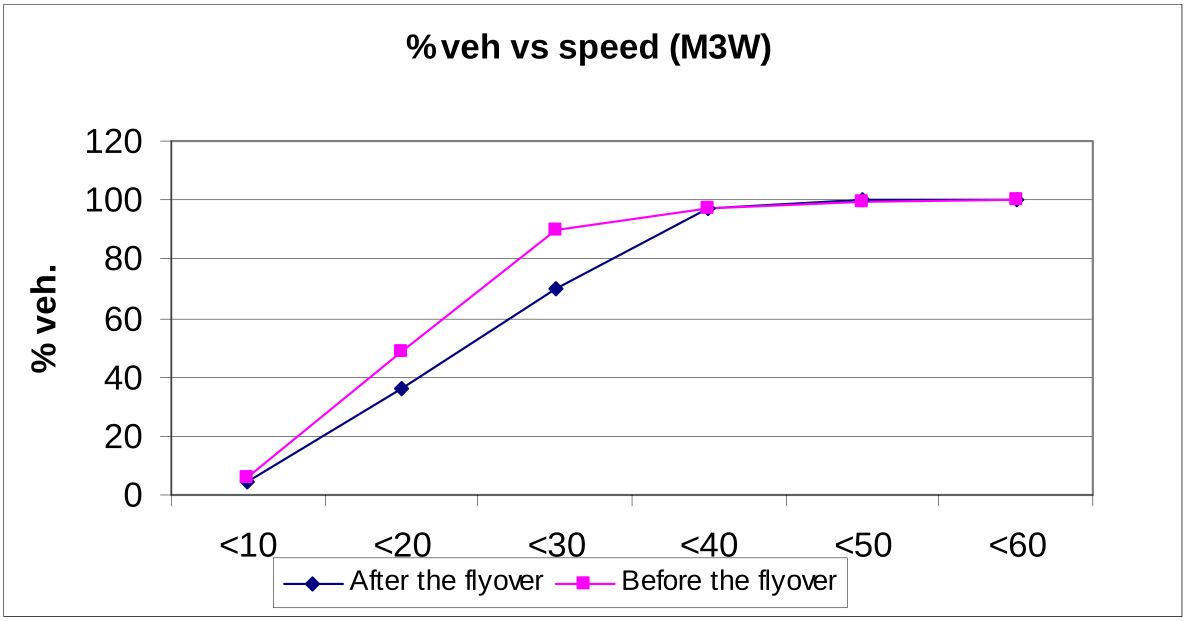

Figure 12. Speed Distribution of Motorized Three-Wheeler Group

Table 4 shows that pedestrians mean waiting time and 90 percent waiting time in Stage 2 and Stage 3 is more than Stage 1 and Stage 4. The mean waiting time and 90 percent waiting time in Stage 4 is less than or equal to one second meaning that most pedestrians do not wait in Stage 4.

5. SUMMARY

Error! Reference source not found. shows that the pedestrian sample attributes before and after reconstruction. Gender wise, the pedestrians sampled remained roughly the same percent composition. Age wise, the percent composition remained approximately the same.

For those pedestrians who crossed at risk, average accepted gap decreased in the after reconstruction case. They accepted greater risk in each stage of crossing primarily because of the higher average speeds of the vehicle groups. The speeds increased 21.6%, 22.6%, 15%, 31.6 % for the heavy vehicle, car, motorized three-wheeler, and motorized two wheeler groups, respectively. The probability of pedestrian fatality with a specific vehicle group increase 67 percent, 100 percent, 100 percent, and 200 percent, respectively.

The pedestrian platoon phenomena observed from the median railing barrier in the after reconstruction case had temporary effects on motor vehicle traffic. This impact resulted in the increase in the standard deviation of speeds 41.7%, 38.2%, 26.7%, 27.9% for heavy vehicles, car, motorized three-wheelers, and motorized two-wheeler groups respectively.

Twenty two percent of pedestrians accepted a risk despite the presence of a nearby pedestrian underpass. The survey showed an interesting aspect of pedestrian behavior in the distance they are willing to use an underpass. Assuming pedestrian traffic between Safdarjung Hospital and AIIMS is minimal and the two bus stands are the source of all pedestrian traffic to the two medical institutions then 85.5% were willing to walk 11 m to the underpass. Approximately, 61.5% were willing to walk 45 m to use the underpass. It is important to place bus stands near the underpass or put the underpass near the bus stand. Further, underpass designs should not have large elevation differentials with the surface street and long tunnel lengths, and should provide more daylight to filter into the tunnel; newer 'open-air' underpasses with shallow depths, with slightly raised street heights, and with short tunnel lengths encourage more pedestrian usage. If such alternatives are not possible, the percentage of underpass walking usage can still increase with sufficient signage that informs and guides pedestrians to the protected underpass.

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