STUDY OF SAFETY EFFECTIVENESS OF PEDESTRIAN CROSSWALKS USING TRAFFIC CONFLICTS

Gökmen Ergün* and Shukri Al-Senan

Department of Civil Engineering
King Fahd University of Petroleum & Minerals
Dhahran, Saudi Arabia

الخلاصـــة :

بالرغم من أنَّ تورط المشاة في حوادث السيارات داخل المدن يشكِّل اقل من واحد بالمائة فإن ٣٧,٦٪ من الوفيات في هذه الحوادث هم من المشاة (مرجع رقم ١) .

إن خطوط المشاة تُستخدم لتنظيم عبور المشاة في الطرقات وذلك من أجل تقليل حوادث المشاة ، ولكن البحوث المتعلقة بفوائد الخطوط المُعلَّمة تشير الى تناقض النتائج . وهدف هذه الدراسة إجراء اختبارات إضافية لمعرفة فائدة هذه الخطوط (خطوط المشاة المُعلَّمة) في تقاطعات المدينة . وقد استُخدم في هذه الدراسة التصوير التلفازي لإحصاء التضارب الناتج بين المشاة والمركبات ومخالفات المشاة في قطع الشارع . وقد استُخدمت هذه الإحصاءات لاختبار فائدة هذه الخطوط . ولقد كانت العينة تشمل تسعة تقاطعات فيها تحكم بالإشارات الضوئية ، وسبعة تقاطعات غير متحكم بها إطلاقا . ولقد دُرست كل من هذه التقاطعات على مدى فترتين لمدة ثلاثين دقيقة .

والنتائج تشير الى فائدة خطوط المشاة لتقليل معظم أنواع التضاربات بين المشاة والمركبات عند التقاطعات الموجود بها إشارات ضوئية . إضافة إلى عدم نفعية هذه الخطوط عند التقاطعات غير المتحكم بها إطلاقا .

*Address for correspondence:
KFUPM Box No. 422
King Fahd University of Petroleum & Minerals
Dhahran 31261
Saudi Arabia

ABSTRACT

Although less than one percent of all urban motor accidents involve pedestrians, 37.6 percent of all urban accident fatalities are pedestrians [1]. Crosswalks are used for the orderly crossing of roadways by pedestrians in order to reduce pedestrian accidents. However, research related to the safety effectiveness of painted crosswalks indicates some conflicting results. This study aims to make a further teest of the usefulness of painted crosswalks at urban intersections.

Pedestrian-vechicle conflicts and pedestrian-crossing violations, which were counted from video-recordings taken at various intersections were used for testing the effectiveness of the crosswalks. Nine signalized and seven uncontrolled intersection approaches were studied for two 30 minutes periods.

Results indicate that crosswalks are effective in reducing the most frequent types of conflicts at signalized intersections. No benefits were observed at uncontrolled intersections.

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INTRODUCTION

Although only 0.4 percent of all urban motor vehicle accidents involve pedestrians, 37.6 percent of all urban fatality accidents in the United States are pedestrian accidents [1]. In Saudi Arabia, 21.5 percent of the urban accidents are pedestrian accidents [7]. These statistics indicate that pedestrian accidents are more severe than the average accident and deserve a special attention.

A crosswalk is one of the facilities which is used for the orderly crossing of intersections and roadways by pedestrians in order to reduce pedestrian accidents. However, research related to the safety effectiveness of painted crosswalks (such as Herms [3], Knoblauch *et al.* [4]) indicates some conflicting results. This study aims to make a further test of the usefulness of painted crosswalks at urban intersections through the study of pedestrian–vehicle conflicts.

REVIEW OF LITERATURE

The "Manual on Uniform Traffic Control Devices" [5] defines the role of crosswalk marking at signalized intersections and across intersectional approaches on which traffic stops to be primarily to guide pedestrians in the proper paths. At locations on which traffic is not controlled by traffic signal or stop signs, crosswalks are used to warn the motorist of a pedestrian crossing point.

There is some controversy about the safety effectiveness of the crosswalks which is also reflected in their use. For instance, Vallette and McDivitt's study [8] of nineteen cities in the U.S.A. revealed that there was an apparent trend toward de-emphasizing the indiscriminate marking of all crosswalks. The reason quoted, in almost all cities, was the Herms' study [3] which intimated that pedestrians are less aware or careful in marked crosswalks than they are in unmarked crosswalks.

Herms' study [3] which used the number of pedestrians as the only exposure measure, indicated that approximately twice as many pedestrian accidents occur in marked crosswalks as in unmarked crosswalks. This study suffers from using an incomplete exposure measure, *i.e.*, volume of pedestrians. Conflict causing vehicle counts were not included in the exposure measure.

A more recent study, made by Knoblauch *et al.* [4], using hazard scores based on a more properly defined exposure measure, PV, the number of pedestrians (P) times the number of vehicles (V) indicated that sites with marked crosswalks were far less hazardous than sites with locations with no marked crosswalks.

RESEARCH METHODOLOGY

The safety effectiveness of crosswalks was assessed through the observation of pedestrian–vehicle conflicts and pedestrian-crossing violations as surrogates for accidents because accident records in Saudi Arabia are not detailed enough to carry out a study of this nature.

Traffic conflicts are a measure of the potential for traffic accidents and occur when a driver takes an evasive action to avoid collision. In recent years, few studies have been conducted toward the application of traffic conflict techniques in pedestrian safety studies (Cynecki [2]; Zegeer, Randolph, Flak, and Bhattacharya [10]; Zegeer, Cynecki, and Opiela [9]).

The conflict and pedestrian violations selected for use in this analysis included the following:

1. Conflict (Behavior) Measures

a) Pedestrian hesitation (PH): Pedestrian momentarily reverses his or her direction of travel in the traffic lane, or the pedestrian hesitates in response to a vehicle in a traffic lane.

b) Aborted Crossing (AC): Pedestrian steps off curb but later reverses direction back to the curb.

c) Moving vehicle (MV): Through traffic is moving through the crosswalk within 20 ft of a pedestrian in a traffic lane.

d) Right-turning vehicle (RT) interaction: Pedestrian is in the path and within 20 ft of a right-turning vehicle.

e) Left-turning vehicle (LT) interaction: Pedestrian is in the path and within 20 ft of a left-turning vehicle.

f) Running pedestrian conflict for through-vehile (RP): Pedestrian runs in a traffic lane in an effort to avoid a collision with a vehicle.

g) Run from turning vehicle (RTV): Pedestrian runs on a traffic lane in response to a turning vehicle or potential turning vehicle.

h) Intersection Dash (ID): Pedestrian runs inattentively at intersection (no oncoming vehicles).

i) Dart out (DO): Pedestrian suddenly appears or runs between parked vehicles.

j) Multiple Threat (MT): One or more vehicle stops for the pedestrian. One or more vehicle on the other lanes do not stop and cause a conflict.

2. Violation (Compliance) Measures

a) Pedestrian starting on the prohibited interval (PPI).

b) Pedestrian jay walking (JWALK), *i.e.*, walking diagonally through the intersectional area.

Conflict and violation counts for selected intersection approaches were carried out as explained in the data collection section below.

The experimental design for the study is shown in Table 1. It should be noted that the effect of crosswalks were planned to be analyzed for signalized and uncontrolled intersections separately. The number outside the parenthesis shows the actual number of intersection approaches studied for a 30 minute period and the number in parenthesis shows the number of studies originally planned. The selection of the study sites was based upon intersection approaches. However, once an approach was selected, all of the other approaches in the intersection were studied. This resulted in more study approaches in some categories than originally planned. While it was realized that the sample sizes were small and the study results would have been more conclusive with larger samples, budgetary limits dictated these sizes.

Conflict, pedestrian, and vehicular traffic counts were obtained from video recordings at the selected intersections. These recordings were made usually from top of a suitable high apartment building near the intersection. Pedestrian activities were brisk in the late afternoons so the video films were shot starting at 4:00 PM and ending at 6:30 PM when visibility had been considerably reduced. In all the filming, there was at least a minimum of 2 hours of continuous recording.

Conflicts and traffic volumes were counted using the forms developed for this purpose from the video recordings for each intersection approach separately. The counting periods were 4:00–4:30 and 5:00–5:30 PM. The graduate students used for conflict, pedestrian violation, and volume counts were given a special training. At the end of this training, each of these students was asked to count conflicts, violations, and volumes at the same intersection during the same time from the films. Inconsistencies between conflict counts were discussed with the students, clearing any misconceptions. This was continued until all students started having consistent counts of conflicts and violations. At this stage, they started doing the actual counts.

Table 1. Experimental Design.

Intersection Control	Number of 30 min. Observation Intervals Studied at Intersection Approaches (Originally Proposed)	
	Presence of Painted Crosswalk	
	Without	With
Signalized	12 (4)	4 (4)
Uncontrolled	8 (4)	6 (4)

The intersection layouts were obtained from an inventory study for each of the filmed intersections. This layout was used to code data related to geometric and other characteristics of the intersection. Finally, using a coding manual, the data were coded, thoroughly checked and prepared for data analysis. Checks included out-of-range values, logical checks, and checks for empty fields.

ANALYSIS

The means and standard deviations for all conflicts and pedestrian violations are presented in Table 2. Comparisons without consideration of exposure might be misleading. However, some general observations can be made from this Table. The most frequent conflicts, at a descending order, are MV followed by LT, RT, RP... at signalized intersections with crosswalks. At those signalized intersections without crosswalks, the most frequent conflicts, in descending order, are RT, MV, RTV, RP, ID....., a somewhat different ordering than those with crosswalks. In general, there seems to be fewer number of conflicts and pedestrian violations at signalized intersection approaches with crosswalks than at those without a crosswalk.

Inclusion of crosswalks at uncontrolled intersection approaches seems to reduce some frequently occurring conflicts and violations; however, it also increase conflicts related to turning vehicles

Table 2. Conflict and Violation Counts.

Conflict and Violation Types (Codes) Explanation		Averages (Standard Deviations) of Conflicts and Pedestrian Violations			
		Signalized Intersections		Uncontrolled Intersections	
		With Crosswalk	Without Crosswalk	With Crosswalk	Without Crosswalk
(PH)	Pedestrian Hesitation	2.00 (2.20)	3.00 (3.56)	2.83 (1.94)	1.50 (1.20)
(AC)	Abort Crossing	0.25 (0.45)	0.75 (1.50)	0.00 (0.00)	0.25 (0.47)
(MV)	Moving Vehicle	9.42 (6.68)	18.00 (6.48)	13.17 (8.67)	23.00 (17.54)
(RT)	Right Turning Vehicle	3.83 (5.01)	24.75 (14.55)	6.33 (7.17)	2.13 (3.94)
(LT)	Left Turning Vehicle	4.50 (5.28)	11.75 (10.08)	8.33 (5.31)	1.13 (1.73)
(RP)	Running Pedestrian	3.00 (3.95)	8.50 (10.66)	1.00 (1.55)	1.63 (1.93)
(RTV)	Running from Turning Vehicle	2.83 (4.61)	10.75 (5.61)	0.50 (0.84)	0.13 (0.35)
(ID)	Intersection Dash	1.58 (1.44)	3.75 (5.19)	0.83 (0.98)	0.25 (0.46)
(DO)	Dart Out	0.50 (1.00)	0.25 (0.50)	0.00 (0.00)	0.13 (0.35)
(MT)	Multiple Threat	2.17 (3.49)	3.25 (3.40)	0.50 (1.22)	1.50 (2.14)
(JWALK)	Jay Walk	0.83 (1.03)	1.00 (0.82)	1.33 (1.86)	2.50 (1.60)
(PPI)	Pedestrian Crossing at Prohibited Interval	19.08 (10.58)	28.00 (17.64)	N.A.	N.A.

N.A. = Not Applicable.

(RT, LT, and RTV). The only pedestrian violation (JWALK) seems to be slightly less at those intersections with a crosswalk.

One of the reasons for conflicting results in the past could be the use of an inappropriate measure of exposure. The exposure measure used in this study is calculated as the product of conflict-causing vehicular volumes for an approach by the number of pedestrians crossing at that approach. Conflict-causing vehicular traffic for a study approach is given in Figure 1. In the remainder of this study, conflict rates (which are obtained by dividing the conflicts of the approach by the product of conflict causing vehicular traffic and pedestrian counts of the approach) are used.

Testing of differences between intersection approaches with and without crosswalks was made using "t-test" which is calculated using the following formula (see SAS [6] for further details).

$$t = \frac{\bar{x}_1 - \bar{x}_2}{\sqrt{(S_1^2/n_1 + S_2^2/n_2)}} \qquad (1)$$

where

$\bar{x}_1$, $\bar{x}_2$ are the average conflicts for groups 1 and 2;

S_1^2, S_2^2 are the sample variances for groups 1 and 2; and

n_1, n_2 are the number of observations in groups 1 and 2.

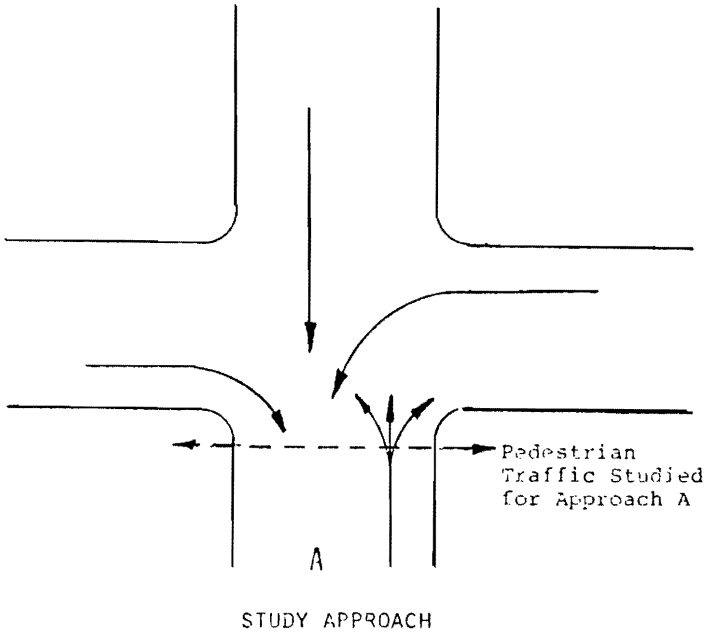

Figure 1. Pedestrian Conflict Causing Traffic Movements for Approach A.

The null hypothesis tested here is:

$$H_o : \bar{x}_1 = \bar{x}_2 .$$

Tests for signalized intersections and uncontrolled intersections were performed separately. The results of t-tests for testing the effects of crosswalks at signalized intersections are presented in Table 3. Mean conflict rates are presented in Figure 2. As can be

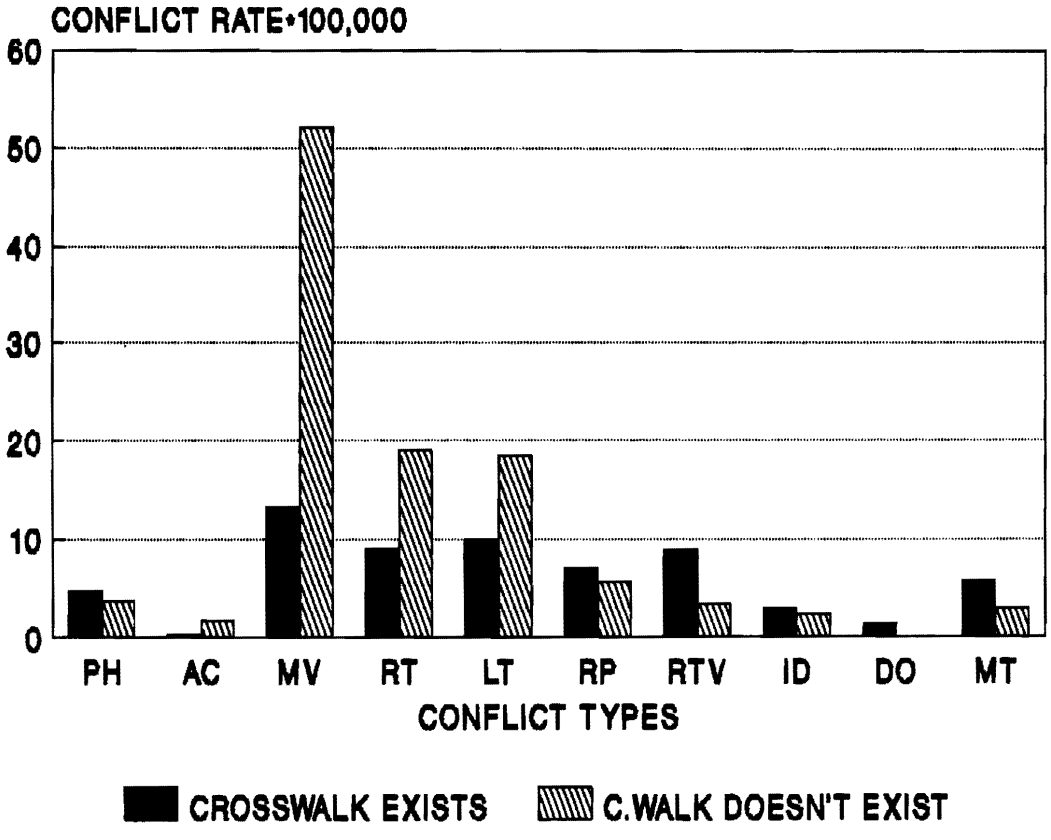

Figure 2. Conflict Rates for Signalized Intersections.

Table 3. Testing the Effect of Crosswalks on Conflicts at Signalized Intersections in Dammam.

Code of Conflict Types	*t*-test (Significance)
PH	0.48 (0.64)
AC	1.07 (0.30)
MV	*2.97 (0.01)*
RT	1.10 (0.29)
LT	0.79 (0.45)
RP	0.65 (0.53)
RTV	*3.10 (0.01)*
ID	0.42 (0.68)
DO	1.64 (0.20)
MT	1.56 (0.15)

seen from this Table and Figure, there are significant differences in Moving Vehicle (MV) and Running From Turning Vehicle (RTV). MV is the most frequently occurring conflict and with respect to this conflict type, intersections with crosswalks seem to be safer. However, intersections without crosswalks had significantly lower RTV conflict rates than those with a crosswalk.

It should be noted that MV conflicts which occur at higher speeds than turning conflicts can be more hazardous. Also, the conflict rate of MV (52.14) is much higher than RTV (3.41) and even if RTV increases a little, because much larger reductions in MV occur, the safety of intersection will improve. Also, part of the reason for higher RTV rates at approaches with crosswalk than those without one could be that pedestrians falsely feel safe and secure on a crosswalk, and thus do not cross traffic very carefully. This behavior can be improved. For example, Zegeer *et al.* [9] showed that a motorist yield sign stating "YIELD TO PEDESTRIANS WHEN TURNING" and a pedestrian warning sign stating "PEDESTRIANS WATCH FOR TURNING VEHICLES" were both found to be effective in reducing right-turn conflicts. With the help of such signs, crosswalks at signalized intersections may be effective in improving safety.

The results of *t*-tests for the effects of crosswalks at uncontrolled intersections are presented in Table 4. The mean conflict rates are given in Figure 3. As can be seen from Table 4, the only significant difference (and with a significance level of 0.06) is for PH conflict and in this type more conflicts occur with a crosswalk. Therefore, it seems that crosswalks at uncontrolled intersections are of no use and perhaps should not be used.

To test the difference in two observations of pedestrian behavior, *i.e.* JWALK and PPI, first all these were converted into percentages. To do this, both JWALK and PPI were divided by total number of pedestrians and multiplied by 100, thus obtaining new variables of percent of pedestrians jaywalking (PERJWALK) and percent crossing on prohibited signal (PERPPI). Table 5 includes the mean rates of PERJWALK, PERPPI and the results of *t*-tests. As can be seen from this Table, crosswalks do not seem to affect pedestrian violations in a significant way.

Table 4. Effect of Crosswalks on Pedestrian Conflicts at Uncontrolled Intersections.

Code of Conflict Types	*t*-test (Significance)
PH	*2.22 (0.06)*
AC	1.52 (0.17)
MV	0.94 (0.37)
RT	1.71 (0.14)
LT	0.99 (0.36)
RP	0.25 (0.81)
RTV	0.74 (0.48)
ID	1.09 (0.30)
DO	1.00 (0.35)
MT	1.07 (0.30)

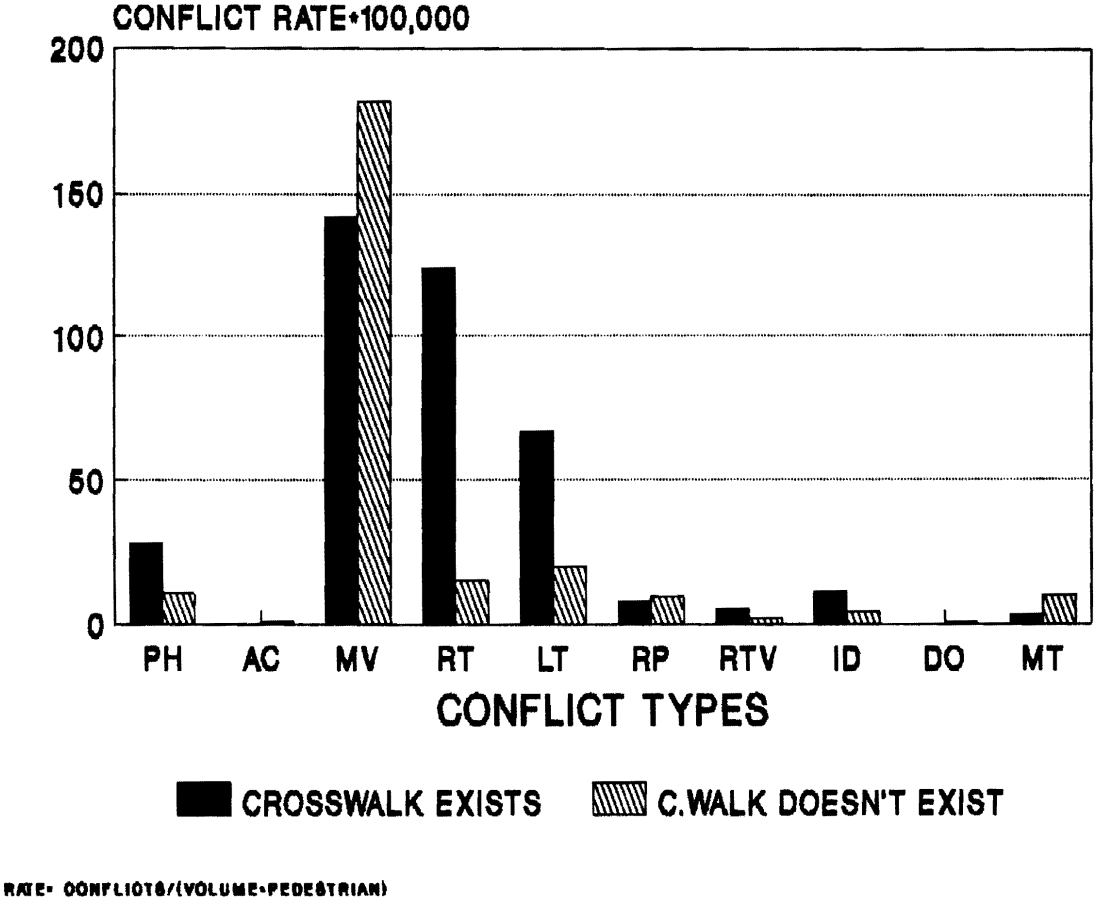

Figure 3. Conflict Rates for Uncontrolled Intersections.

Table 5. Effects of Crosswalks on Pedestrian Behavior.

Location	Behavioral Item	Average Percentages at Intersection Approaches		*t*-test (Significance)
		With Crosswalk	Without Crosswalk	
Signalized Intersections	PER JWALK	0.47	0.58	0.25 (0.80)
	PER PPI	29.58	24.65	0.46 (0.67)
Uncontrolled Intersections	PER JWALK	3.64	6.79	1.06 (0.31)

CONCLUSIONS AND RECOMMENDATIONS

The main conclusions of this study are as follows:

1. Pedestrian crosswalks can be effective at signalized intersections especially in reducing moving vehicle (MV) conflict. Although some right turning (RTV) conflicts increase a little, these are not as dangerous and as frequent as MV conflicts and there is evidence in the literature that they can be reduced by some signs for vehicles and pedestrians (a yield sign stating "YIELD TO PEDESTRIANS WHEN TURNING" and warning sign for pedestrians stating "PEDESTRIANS WATCH FOR TURNING VEHICLES"). Therefore, it seems that crosswalks can be effectively used in improving safety of signalized intersections.
2. At uncontrolled intersections, crosswalks seem to have no significant effect on conflicts and in fact they increase one special type (PH = Pedestrian Hesitation). Therefore, the use of crosswalks at uncontrolled intersections may not be advisable for safety considerations alone.

Recommendations for future work are listed below:

1. The conclusions of this study are based upon small sample sizes and need to be confirmed with similar work in the future.
2. An important step in future research will be to establish the relationships between the pedestrian conflicts studied in this work and accidents, especially the severity of accidents. The current pedestrian accident records in Saudi Arabia are not yet reliable enough to do this now. But efforts have been made to compile reliable and detailed accident records and such a task will be possible in the near future.

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