Safety of Pedestrian Crossings at Signalized Intersections

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In Israel three basic pedestrian crossing provisions are common at signalized intersections: an uncontrolled (but marked) crossing at a right-turn filtering lane; a pedestrian crossing phase concurrent with the vehicle phase (which may produce conflicts with turning vehicles); and an exclusive pedestrian phase, completely separating pedestrians from turning vehicles. The relative risk of these crossing-turning designs was evaluated through accident analysis. The data base consists of information about geometry, traffic, and operational characteristics of 320 signalized intersections in Tel Aviv, Jerusalem, and Haifa, and details of 5,132 vehicle accidents and 1,310 pedestrian accidents that occurred at those intersections during 1977–1982. The relationship between crossing type and average number of accidents per intersection was tested while factors known to affect accident level—vehicle volume, pedestrian activity, and intersection complexity—were controlled for. Pedestrian accidents were indeed influenced by these factors, but the various crossing types had little effect, if any, on the number of pedestrian accidents, and no effect on the number of vehicle collisions. There was some indication that exclusive and concurrent phases provide different degrees of pedestrian protection in particular combinations of vehicle and pedestrian volumes.

With the ever-increasing demands for improved safety and operational efficiency of signal-controlled intersections, many aspects of intersection and signal design are being critically reexamined *(1–3)*. Provisions for pedestrians crossing at signalized intersections are of particular concern because of the vulnerability of pedestrians and because of the apparent increase in delays and operational and maintenance costs involved in pedestrian signals and other provisions.

Zegeer et al. *(4)* concluded that there was no significant difference in the pedestrian accident experience of standard signal-controlled intersections compared with similar intersections in which pedestrians cross concurrently with vehicles. Robertson and Carter *(1)* reported similar findings. Knoblauch et al *(5)*, on the other hand, report a lower hazard index for intersections equipped with pedestrian signals compared with intersections without special pedestrian indications. A hazard index as estimated in that study is the ratio of accidents to exposure.

It might be expected that an exclusive pedestrian phase would demonstrate a positive safety effect for pedestrians. However, the number of such installations in the United States is not very large, because traffic engineers are reluctant to use them *(1)*. In their data base of 1,300 intersections, Zegeer et al. *(4)* had only 109 intersections equipped with an exclusive pedestrian phase. The arrangement showed a probable safety advantage only at high pedestrian and vehicle volumes.

Concern with pedestrian safety at signalized intersections revolves around vehicle turning movements. This is because in most applications the signal-timing program does not separate crossing pedestrians and turning vehicles [right turn on green (RTOG) and left turn on green (LTOG)]. The right-turn-on-red (RTOR) maneuver adds yet another potential conflict with pedestrians at both ends of the turning movement *(3)*.

Table 1 shows the distribution of pedestrian accidents by direction of vehicle movement as reported in several U.S. studies and in Israel. It can be seen that the majority of pedestrian accidents at signalized intersections involve vehicles going straight ahead (a small percentage involve vehicles backing up). The proportion of accidents related to turning in the U.S. studies and in Israel is 30 to 45 percent. The Israeli figures are based on the total national accident file for 1980–1982. More than 90 percent of the 850 pedestrian accidents at signalized intersections were on urban streets.

Left-turn maneuvers are generally considered more hazardous for pedestrians than right-turn maneuvers *(1)*, a conclusion reflected by the U.S. data in Table 1. When the proportions of turnign vehicles are considered (15 to 25 percent are typical design assumptions), the hazard associated with turning vehicles is higher than that for those going straight ahead *(1, 7)*. However, unlike previous results, Knoblauch et al. *(5)* found similar exposure ratios for left- and right-turning vehicles (7 to 8 percent) and a lower hazard index compared with that for vehicles going straight ahead.

The RTOR maneuver, on the other hand, was found by Knoblauch et al. *(5)* to have a relatively high hazard index—it accounted for a small percentage (1.6 percent) of pedestrian accidents, but for an even smaller percentage (0.5 percent) of turning vehicles in the exposure data.

In Israel the smaller proportion of accidents associated with left-turning compared with right-turning vehicles can be attributed to the provision in the signal program of an exclusive or nonconflicting phase for all left-turning vehicles. During this phase, pedestrians usually face a Don't Walk indication.

How can the conflict between turning vehicles and crossing pedestrians be minimized? Zegeer et al *(8)* and Zegeer and Cynecki *(3)* list numerous design alternatives to enhance clarity of signals, alert pedestrians or motorists, decrease pedestrian delays, and improve compliance. Chadda and Schonfeld *(9)* suggest the use of exclusive right-turn lanes as an engineering

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TABLE 1 PEDESTRIAN ACCIDENTS AT SIGNALIZED INTERSECTIONS: DATA FROM UNITED STATES AND ISRAEL

	Percentage of Accidents by Vehicle Direction					
Study	Left Turn	Right Turn	Straight and Other	No. of Accidents	No. of Intersections	Source of Study Data
United States						
Fruin *(6)*	31	14	55	172	32	One-way grid intersections, Manhattan
Habib *(7)*	25	13	62	455	45	One-way grid intersections, Manhattan
Zeeger et al *(4)*	22	15	63	2,081	1,297	Fifteen cities
Robertson and Carter *(1)*	17	12	71	202	62[a]	Washington, D.C., area
Israel	13	17	70	850	520	All signalized intersections

[a] Of which 54 were signalized.

countermeasure for preventing pedestrian–vehicle conflicts at RTOR-type turns. Pedestrian signalization practices in Israel provide an opportunity to evaluate the effectiveness of three basic crossing arrangements that are also used in the United States.

PEDESTRIAN SIGNALIZATION PROVISIONS IN ISRAEL

All traffic signals are equipped with pedestrian indications at the zebra-marked crosswalks. Two symbolic indications are used—a red standing man and a green walking man.

Most urban intersections have a separate pedestrian phase at one or more of the intersection legs. A second common provision is a partially concurrent phase with right-turning vehicles. Left turns are usually controlled by a separate indication. Pedestrians have the legal right-of-way, and this fact is emphasized by the provision of a flashing amber beacon with a symbol of a pedestrian facing the right-turning vehicles or a standard sign, Yield to Pedestrian, or both. There is no RTOR provision in the Israeli traffic code.

The third arrangement provides for a separate uncontrolled right-turn lane channeled to merge into the intersecting road. Usually a marked crosswalk diagonally connects the curb to the traffic island, but sometimes a crosswalk is in the usual corner position. In the former case, pedestrians cross to the island without a signal; in the latter, they are still controlled by a pedestrian indication. In either case, drivers are alerted to the crosswalk by a flashing amber beacon and a Yield sign.

Because of delays and capacity considerations, there is a tendency in Israel to convert, wherever possible, an exclusive phase to a separate right-turn lane or to a concurrent-phase arrangement. Yet there are concerns about possible safety trade-offs associated with the more economical crossing provisions. In this study the safety performance of the three pedestrian crossing arrangements at urban signalized intersections is examined.

METHOD

The study is based on analysis of accident data from most of the signalized intersections (317) in the three major cities in Israel—Jerusalem, Tel Aviv, and Haifa—during the period 1977–1982. Detailed characteristics of the geometry and traffic and signal devices at the intersections were collected. These included traffic volumes, level of pedestrian activity, typical approach speed, number of legs and lanes, turning directions on each leg, and type of crossing provision. For each intersection, detailed data on all accidents that occurred during the 6-year period were extracted from the national data file of injury accidents.

The analyses were performed separately for two 3-year periods (1977–1979 and 1980–1982) in order to increase uniformity within each period and to examine the stability of the findings.

The data in the computerized accident file do not include information on the specific location of the accident, so direction of vehicle movement could not be linked to a specific leg of an intersection. Therefore, the unit of analysis was an intersection rather than a leg, and all pedestrian or vehicle accidents were included and not only those related to turning movements.

The basic logic of the analysis is that, given a large enough data base, it is possible to group the intersections so that each group is characterized by a different combination of crossing arrangements. It should thus be possible to detect significant differences in accident frequencies among the groups, if such differences do exist. However, it must be admitted that an analysis at the intersection level may not be sensitive to small differences or to complex associations between specific crossing combinations and accidents.

The intersections were classified into six groups by type of crossing provision, as follows:

1. Complete separation at all legs,
2. Uncontrollable crossing at an exclusive right-turn lane or a concurrent phase at one of the junction's legs,
3. Uncontrolled crossing at two intersection legs (and exclusive phases at all others),
4. Concurrent phases at two legs (and exclusive phases at all others),
5. Concurrent phases at three legs (and exclusive phases at all others), and
6. Mixed arrangements—at least one leg with an uncontrolled crossing and one leg with a concurrent phase.

The classification was constrained by the need to have a sufficient number of intersections in each category for analysis. The following intersection characteristics were used in the analyses: number of entering vehicles [annual average daily traffic (AADT)], level of pedestrian activity, approach speed, number of legs, number of conflict points, and type of crossing provision. Pedestrian activity and approach speeds were rated by traffic engineers who were familiar with the intersections. Pedestrian activity was graded on a three-level scale: low (less than 200 pedestrians crossing at peak hour); medium (200 to

TABLE 2 ACCIDENT STATISTICS FOR 317 URBAN SIGNALIZED INTERSECTIONS STUDIED

	Pedestrian Accidents		Vehicle Accidents		Total	
Statistic	1977–1979	1980–1982	1977–1979	1980–1982	1977–1979	1980–1982
No. of accidents	787	523	2,930	2,202	3,717	2,725
Intersections with no accidents (%)	20	36	6	11		
Avg no. of accidents per intersection	2.48	1.65	9.24	6.95	11.73	8.6
Correlation coefficient between accidents at same intersection during two time periods	$r = 0.49$		$r = 0.79$			

600 pedestrians at peak hour); and heavy (more than 600 pedestrians at peak hour). Approach speed had two levels, low and high. The number of conflict points was determined by the number of legs and the number of turning and through lanes, which reflect the complexity of traffic at the junction.

RESULTS

Table 2 summarizes the accident data for the 317 intersections. Pedestrian accidents accounted for 20 percent of the total in 1977–1979.

During 1980–1982, there was a general decline in urban accidents in Israel, a fact also reflected in Table 2. Pearson correlation coefficients were calculated between the number of accidents at each intersection during the two time periods. The coefficients, for both vehicle and pedestrian accidents, are statistically significant. The lower correlation coefficient between pedestrian accidents during two periods compared with the corresponding coefficient for vehicle accidents reflects the higher variance of pedestrian accidents.

Pedestrian Accidents

The univariate associations between intersection characteristics and the number of pedestrian accidents are shown in Table 3. Univariate associations between number of accidents and the

TABLE 3 PEDESTRIAN ACCIDENTS PER INTERSECTION IN THREE YEARS BY INTERSECTION CHARACTERISTICS

	Accident Data			
	1977–1979		1980–1982	
Category	Avg No. of Accidents	No. of Intersections	Avg No. of Accidents	No. of Intersections
No. of conflicts				
1–6	2.08	109	1.58	108
7–20	2.44	133	1.69	132
21+	3.13	75	1.65	78
No. of legs				
3	1.74	81	1.24	87
4	2.68	216	1.76	212
5+	3.40	20	2.21	19
Approach speed				
Low	2.52	192	1.88	185
High	2.48	105	1.25	113
AADT				
–14,999	1.88	52	1.28	47
15,000–17,999	1.88	40	1.18	38
18,000–21,999	2.74	46	1.96	47
22,000–24,999	2.97	29	2.43	80
25,000–29,999	2.97	40	1.60	40
30,000+	3.67	43	2.09	45
Pedestrian activity level				
Low (< 200 crossings/hr)	1.71	117	1.04	117
Medium (200–600 crossings/hr)	3.12	81	2.40	79
High (> 600 crossings/hr)	3.40	67	2.82	71
Type of crossing provision				
Separate phase	2.33	42	1.78	46
Concurrent or uncontrolled at one leg	2.43	68	1.40	72
Uncontrolled turn at two legs	2.15	33	1.23	39
Concurrent phase at two legs	2.14	83	1.64	75
Concurrent phase at three-plus legs	3.07	60	1.96	55
Mixed arrangements	2.94	31	2.03	30
All intersections	2.48	317	1.65	317

characteristics of the intersections were tested by using a one-way analysis of variance. The average number of accidents per intersection increases with the number of intersection legs, traffic volumes, the level of pedestrian activity, and the number of conflict points. No clear relationship was found with approach speed.

The joint effect of traffic volume and pedestrian activity on accidents is shown in Figure 1. Traffic volumes were dichotomized to those less than and more than 18,000 vehicles (AADT) according to the findings in Table 3. A second possible cutoff point at 30,000 vehicles was not used because of the small number of intersections with such high volumes. Similar cutoff points for the effect of traffic volumes on pedestrian accidents (18,000 and 27,000) were found by Zegeer et al. *(4)*.

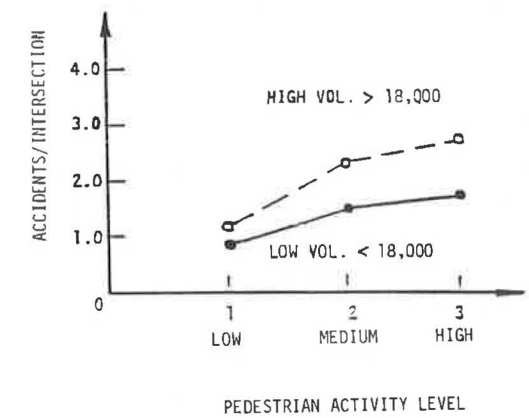

FIGURE 1 Accidents as a function of traffic volume and pedestrian activity.

Both vehicle volume and pedestrian activity are positively correlated with the average number of accidents. The effect of vehicle volume is larger in conjunction with medium or high levels of pedestrian activity. Pedestrian accidents for the period 1980–1982 were also analyzed by pedestrian action, age of casualty, and severity of the accident. Most accidents (83 percent) occurred during crossing; 25 percent were severe or fatal. Of the pedestrian casualties, 15 percent were children under the age of 14, and 21 percent were elderly, aged 65 and over. No differences were found among the different types of crossing arrangements except for a slightly higher percentage of elderly casualties at intersections with a concurrent pedestrian phase at two or more legs. This finding may be related to the higher level of alertness needed when crossing such intersections.

Comparison of Crossing Provisions

The average number of accidents per intersection for the six categories of crossing provision is presented in Table 3. The number of accidents at intersections with mixed provisions and at intersections with a concurrent phase at three of the legs was higher than that for intersections with the other provisions. However, one-way analysis of variance revealed no significant differences among categories.

The net effect of the type of crossing provision, after the effects of other traffic characteristics were controlled for, was evaluated by means of a multivariate analysis of variance. Traffic volume and pedestrian activity had a significant main effect on accidents ($P = .001$), with no interaction effect. The effect of crossing provision after adjustment for vehicle and pedestrian volumes was not significant ($P = .70$). Similar results were obtained for the two time periods. Further analyses containing additional characteristics of the intersections as control variables all revealed the same basic findings: effects of traffic volume and level of pedestrian activity were significant and effects of the type of crossing provisions were not significant.

It was possible that the classification of intersections grouped together intersections that were not homogeneous enough and, consequently, that differences between types of crossing provisions were masked in the analysis. Therefore the analysis was repeated on a subset of 205 intersections that had similar types of crossing provision on most of the intersection legs. The intersections were classified into three groups:

1. Intersections with a separate pedestrian phase on all legs,
2. Intersections with uncontrolled crossings on at least two legs, and
3. Intersections with a concurrent phase on at least two legs.

The mean number of accidents for 2 × 2 combinations of traffic and pedestrian volumes and for each crossing type is given in Table 4. The number of accidents is not shown for cells containing less than six intersections. It seems that the three types of crossing arrangements do not differ when traffic volumes are low. However, when vehicle volumes are high and pedestrian volumes are low, the mean number of accidents for

TABLE 4 PEDESTRIAN ACCIDENTS PER INTERSECTION BY CROSSING TYPE, TRAFFIC VOLUME, AND LEVEL OF PEDESTRIAN ACTIVITY

		1977–1979 Data by Crossing Type						1980–1982 Data by Crossing Type					
		Exclusive Pedestrian Phase		Uncontrolled Crossing (2+ legs)		Concurrent Phase (2+ legs)		Exclusive Pedestrian Phase		Uncontrolled Crossing (2+ legs)		Concurrent Phase (2+ legs)	
Traffic Volume	Pedestrian Activity	Avg. No. of Accidents	No. of Intersections	Avg. No. of Accidents	No. of Intersections	Avg. No. of Accidents	No. of Intersections	Avg. No. of Accidents	No. of Intersections	Avg. No. of Accidents	No. of Intersections	Avg. No. of Accidents	No. of Intersections
Low	Low	–	–	1.9	8	1.6	27	–	–	0.4	10	1.2	21
Low	High[a]	2.6	12	–	–	2.4	28	1.8	14	–	–	1.6	27
High	Low	1.4	7	1.1[b]	14	2.4[b]	25	1.0	8	0.7[b]	18	1.5[b]	25
High	High	3.4	13	4.3	8	4.0	43	3.0	14	3.3	8	2.5	37

[a]Previously medium and high combined.
[b]Differences between means are statistically significant ($P < .05$).

TABLE 5 VEHICLE ACCIDENTS PER INTERSETION IN THREE YEARS BY INTERSECTION CHARACTERISTICS

Category	Accident Data 1977–1979 Avg. No. of Accidents	No. of Intersections	1980–1982 Avg. No. of Accidents	No. of Intersections
No. of legs				
3	7.67	81	5.44	87
4	8.04	78	5.93	72
5+	10.60	159	8.22	159
AADT				
–14,999	4.92	52	3.96	47
15,000–17,999	5.22	40	3.82	38
18,000–21,999	9.00	46	6.72	47
22,000–24,999	8.34	29	6.20	30
25,000–29,999	10.97	40	6.82	40
30,000+	22.44	43	17.60	45
No. of conflicts				
1–6	5.47	109	4.44	108
7–20	9.47	133	6.49	132
21+	14.32	75	11.17	78
Approach speed				
Low	7.50	193	5.20	186
High	12.34	106	9.61	113
Pedestrian activity level				
Low	8.40	113	6.99	113
Medium	10.32	78	7.56	75
High	7.89	61	5.58	65
Type of crossing provision				
Separate phase	8.05	42	5.54	46
Concurrent or uncontrolled at one leg	9.99	68	7.60	72
Uncontrolled turn at two legs	9.24	33	7.36	39
Concurrent phast at two legs	8.45	83	6.11	75
Concurrent phase at three-plus legs	10.57	60	8.29	55
Mixed arrangements	8.81	31	6.63	30

intersections with a concurrent phase is higher than for intersections with the other two provisions—exclusive phase or uncontrolled crossing with a separate turn lane. This result was found for both time periods. However, not all pairwise comparisons were statistically significant. When both vehicle volume and pedestrian activity level are high, a separate phase appears safer than uncontrolled crossing, but the differences were not statistically significant.

Vehicle Accidents

Table 5 shows the mean number of vehicle accidents for various intersection characteristics. The number of accidents increases with traffic volume, number of conflict points, typical approach speed, and complexity of the intersection. As expected, no systematic relationship can be noted with level of pedestrian activity or with type of crossing provisions. The results are similar for the two time periods. These results also were essentially upheld in a multivariate analysis.

DISCUSSION

The main purpose of the study was to compare the level of safety of three basic pedestrian crossing provisions in urban signalized intersections: complete separation in time between vehicles and pedestrians (separate phase); a concurrent phase for pedestrians and turning vehicles (mostly right turns), and a free right-turn lane combined with uncontrolled crossing. The analysis was based on 6-year injury accident data and the characteristics of 317 urban intersections.

Several intersection characteristics are clearly related to increased likelihood of accidents. The most obvious ones are traffic volume and amount of pedestrian activity. The complexity of an intersection as measured by either number of legs or number of conflict points is also related to number of pedestrian and vehicle accidents.

The type of pedestrian crossing provision appears to have only a slight effect on pedestrian accidents and no effect on vehicle injury accidents. Pedestrian and vehicle volumes are the most important factors determining the apparent differences between crossing provisions. At low vehicle volumes (less than 18,000 AADT), it makes little difference which crossing arrangement is provided for pedestrians (within the types used in Israel), irrespective of the level of pedestrian activity. Only at high vehicle and pedestrian volumes might an exclusive pedestrian phase possibly be advantageous. Zegeer et al. *(4)* report a similar conclusion. The concurrent-phase provision appears to be more dangerous to pedestrians compared with the other provisions when vehicle traffic is heavy but pedestrian traffic is light.

In order to understand the relative efficacy of pedestrian crossing provisions, one must consider their operational aspects. For example, the arrangements differ in the delays they cause motorists and pedestrians, which in turn influence the behavior of motorists and pedestrians. Khasnabis et al. *(10)* arrived at a similar conclusion after reviewing the literature.

The actual performance of either a separate or a concurrent pedestrian phase depends on the willingness of drivers to yield to pedestrians and on the compliance of pedestrians with the signal indication. Pedestrians do not necessarily wait for green or their exclusive green. In practice, many utilize gaps in traffic even against a red light. At low traffic volumes, noncompliance does not entail a serious risk, and therefore potential differences between crossing arrangements would be reduced. Paradoxically, it is very likely that noncompliance will be relatively high at separate-phase crosswalks when traffic volume is low, because of larger delays and the perceived lack of justification for waiting.

In a study of RTOR violations by motorists, Zegeer and Cynecki *(3)* observed both RTOR and RTOG violations and conflicts with pedestrians. High rates of violations were associated with low (cross-street) traffic and low pedestrian volume. Intersection geometry that allows an easy right-turn movement also encourages violations. This situation is similar to the exclusive right-turn lane combined with uncontrolled crossing. At high pedestrian and vehicle volumes, pedestrians will have a hard time finding safe gaps for crossing, and under these conditions, the separate-phase provision would have an advantage over other provisions.

With high pedestrian volumes, concurrent provisions might also function reasonably well, because pedestrians can force their right of way and drivers cannot easily ignore them. It would seem that measures to increase the conspicuity of the crosswalk and the driver's obligation to yield to the pedestrian *(8)* could be effective under these conditions. In Israel all concurrent-phase crossing provisions are emphasized with flashing beacons and Yield signs. Nevertheless, at low pedestrian activity and high vehicle volume, these provisions are not as safe as others. The inescapable conclusion might be that at low traffic volumes, pedestrians could fend for themselves fairly well no matter what the provisions were, but at heavy traffic volumes only an unambiguous separate pedestrian phase (or complete spatial separation) can provide an acceptable level of safety for pedestrians while crossing a signalized intersection.

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