Evaluation of Countermeasures Related to RTOR Accidents That Involve Pedestrians

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ABSTRACT

The purpose of this analysis was to field test the most promising countermeasures for right-turn-on-red (RTOR) accidents that involve pedestrians under various site conditions. Seven countermeasures were field tested at 34 intersection approaches in six U.S. cities. Various types of conflicts and violations were used as measures of effectiveness, including RTOR-related events and total (RTOR plus right-turn-on-green) events. The Z-test for proportions was applied to determine the effectiveness of countermeasures. In summary, the red ball NO TURN ON RED (NTOR) sign is more effective than the standard black and white NTOR sign, and it is recommended that it be added to the Manual on Uniform Traffic Control Devices. The offset stop bar improved motorist compliance and reduced conflicts with cross-street traffic and is recommended for use on multilane approaches under some conditions. The electronic NTOR blank-out sign was slightly more effective, although considerably more costly, than traditional signs. The NO TURN ON RED WHEN PEDESTRIANS ARE PRESENT sign was effective at sites with moderate to low volumes of RTOR vehicles, although the legend is difficult to read when located adjacent to the signal or on the far side of the intersection.

Past research has failed to clearly demonstrate the types of countermeasures that will most likely minimize the adverse effects of a right-turn-on-red (RTOR). A wide variety of site conditions, such as geometrics, vehicle speeds, traffic volumes, pedestrian activity, and other factors, may affect the safety and operations of RTOR maneuvers. Thus there is a need to develop and test countermeasures that would reduce the likelihood of a pedestrian accident involving RTOR vehicles at sites with various characteristics.

The primary RTOR accident countermeasure used to date has been a prohibition of RTOR. Full-time (24-hr) as well as part-time prohibitions have been used. However, there is strong evidence that RTOR prohibitions are not always the best solution when a problem exists. An unwarranted RTOR prohibition may result in a high violation rate and an enforcement problem.

This study is part of a larger study on RTOR, conducted for the FHWA, that addressed motorist compliance with RTOR, warrants for RTOR prohibition, and an evaluation of countermeasures to RTOR-related problems (1). The purpose of this paper is to report the results of field testing of RTOR-related countermeasures, particularly as they relate to pedestrian safety.

The general types of countermeasures that were considered in this analysis included physical roadway improvements such as (a) signing options, (b) signal modifications, (c) pavement markings, (d) design changes, and (e) other treatments such as adding intersection lighting and removing roadside clutter. Selective traffic enforcement and public (driver or pedestrian) education programs are recognized as potential treatments for an RTOR problem. It is also recognized that changes in local or national laws governing RTOR could affect RTOR safety and operations. However, the development and testing of countermeasures in this study was limited to physical roadway improvements only.

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BACKGROUND

A limited number of countermeasures for RTOR accidents are identified in the literature. Parker (2) developed a list of recommendations to consider when implementing RTOR prohibitions. These considerations included (a) increasing sign size, (b) illuminating the NTOR sign, (c) modifying sign location (post mounted or overhead), (d) improving legislation and enforcement to protect pedestrians in RTOR situations, (e) offsetting stop bars to allow a "clear view" for motorists in the right lane, (f) improving public awareness of RTOR regulations and safety, (g) "fine tuning" traffic signal timing, and (h) replacing or installing presence detectors that are traffic actuated at intersections to improve the efficiency of traffic operations.

McGee (3) also developed some recommendations for RTOR and RTOR prohibitions; these included improving the wording of sign messages prohibiting RTOR, providing variable RTOR time restrictions (i.e., during school hours or specific times or days), installing more than one sign prohibiting RTOR on the approach, using YIELD TO PEDESTRIAN signs in areas of high pedestrian volumes, and using RIGHT TURN ON RED AFTER STOP signs.

In their 1981 study of RTOR related to pedestrians and bicyclists, Preusser et al. (4) suggested several potential countermeasures worthy of further analysis and development, including (a) providing bicyclist and pedestrian education programs, (b) modifying warrants for RTOR prohibition to include consideration of bicycle traffic, (c) using exclusive pedestrian signal phasing that would include an illuminated NO TURN ON RED message, and (d) setting back the pedestrian crosswalk so the pedestrians would cross the street behind the RTOR vehicle.

In 1984 Technical Committee 4A-17 of the Institute of Transportation Engineers developed guidelines for prohibiting RTOR (5). Some of their study recommendations addressed countermeasures related to RTOR including (a) using a disappearing-legend sign for part-time prohibitions and approaches near railroad crossings, (b) considering less restrictive prohibition signs instead of full prohibitions (i.e., NO TURN ON RED TO HENRY STREET), and (c) providing education and enforcement programs.

DEVELOPMENT OF COUNTERMEASURES

The development of countermeasures for RTOR-pedestrian accidents may be based on the sequence of events leading to such an accident, as well as on the actions and contributing causes. For example, Figure 1 shows the sequence of events of RTOR-pedestrian accidents beginning with the total population of signalized intersection approaches. Vehicles turning right on red (whether permitted or prohibited), when combined with pedestrians, may lead to accidents. When evasive action is taken by either the driver or pedestrian, an RTOR-pedestrian accident is avoided. However, when neither reacts in time, an RTOR-pedestrian accident results.

It may be possible to prevent an RTOR-pedestrian accident by interjecting countermeasures at two specific stages in the sequence of events, namely, at points A and B as shown in Figure 1. Actions at point A address the problem of vehicles turning right on red, even though an RTOR prohibition exists on the approach. Countermeasures of this type are designed to reduce RTOR violations.

At point B in Figure 1, motorists turn right on red with pedestrians present, and neither the drivers nor the pedestrians take adequate evasive action to avoid an RTOR-pedestrian accident. Countermeasures directed at point B would involve primarily changing the behavior or awareness of pedestrians or motorists.

The development of countermeasures for field testing in this study involved treatments to break the chain of events that leads to an RTOR-pedestrian accident.

SELECTION AND FABRICATION OF COUNTERMEASURES

A preliminary assessment of 30 countermeasures resulted in the selection of the following seven for field testing:

1. A NO TURN ON RED sign with a red ball in the center (Figure 2)--Because of the preponderance of signs and information at many intersections, the red ball sign is expected to be more eye catching and symbolic in nature.
2. Larger 30- x 36-in. (75- x 90-cm) NO TURN ON

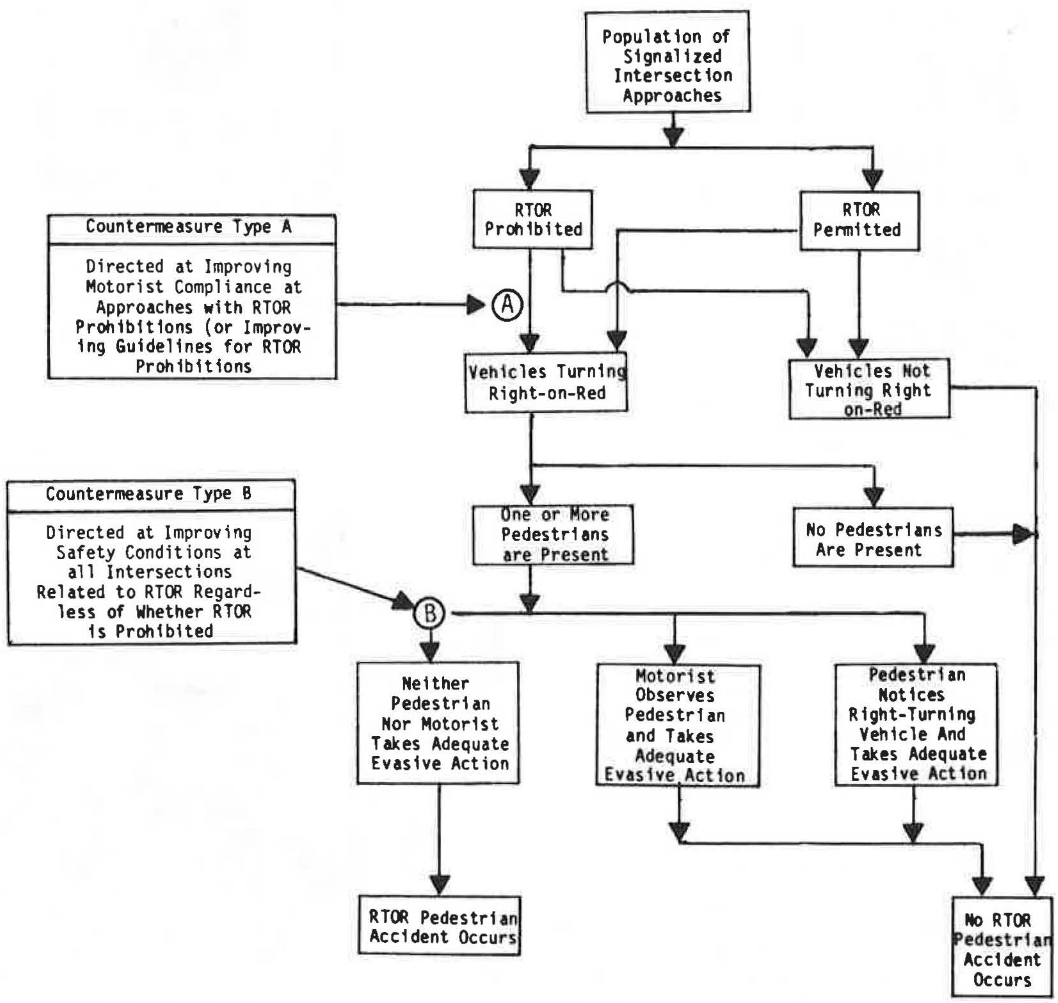

FIGURE 1 Application of countermeasure types to the chain of events for RTOR-pedestrian accidents.

FIGURE 2 Countermeasure 1.

RED sign (Figure 3)--At intersections where the standard-sized 24- x 30-in. (60- x 75-cm) sign is not easily seen, such as on the far side of a wide intersection, the larger sign is expected to be more conspicuous.

3. NO TURN ON RED WHEN PEDESTRIANS ARE PRESENT sign (Figure 4)--The WHEN PEDESTRIANS ARE PRESENT supplementary message was thought to be preferable to time-designated restrictions. This would allow motorists to turn right on red when conditions allowed but would require them to yield to pedestrians.

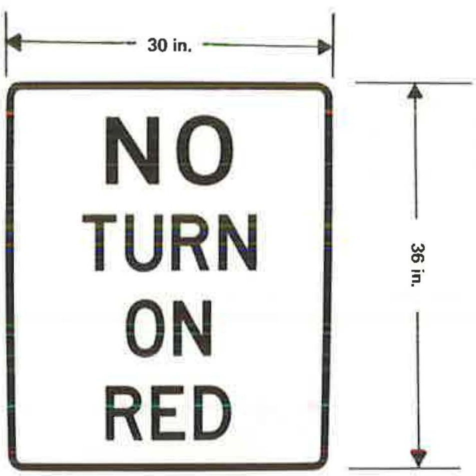

FIGURE 3 Countermeasure 2.

4. A red ball NO TURN ON RED sign with a WHEN PEDESTRIANS ARE PRESENT legend (Figure 5)--This is intended to test the combination of countermeasures 1 and 3.

5. Offset stop bar (Figure 6)--This is intended to provide improved sight distance to RTOR vehicles in the right lane by moving back the stop bar of adjacent stopped vehicles (in the left or middle lanes) by approximately 6 to 10 ft (1.8 to 3 m). Thus RTOR motorists are provided a better view of cross-street and pedestrian traffic coming from the left.

6. LOOK FOR TURNING VEHICLES pavement marking in the crosswalk (Figure 7)--This low-cost countermeasure is intended to remind pedestrians to be alert for turning vehicles, including RTOR vehicles.

7. Variable message NO TURN ON RED blank-out sign (Figures 8 and 9)--This is another alternative to a time-designated RTOR prohibition that would illuminate the NO TURN ON RED message only during times, seasons, days, or intervals when RTOR prohibition is justified.

FIGURE 4 Countermeasure 3.

FIGURE 5 Countermeasure 4.

FIGURE 6 Countermeasure 5.

FIGURE 7 Countermeasure 6.

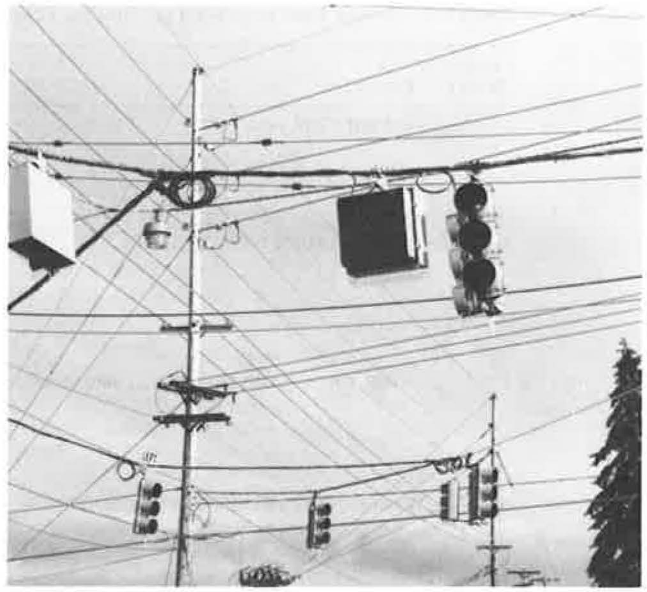

FIGURE 9 Countermeasure 7 not illuminated.

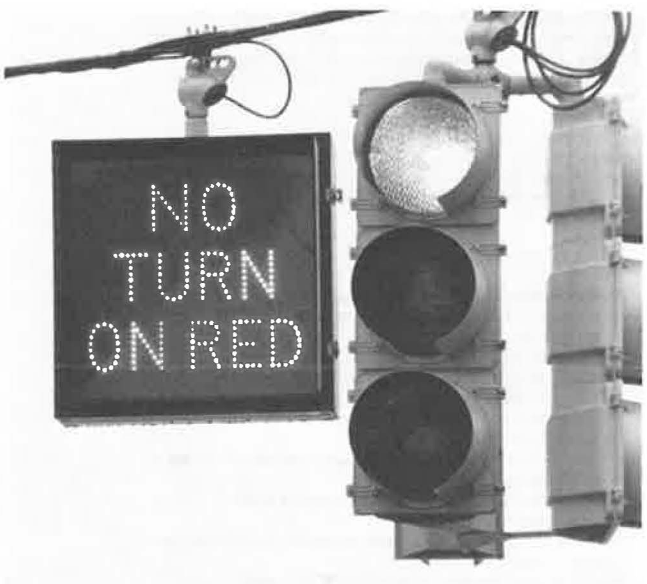

FIGURE 8 Countermeasure 7 illuminated.

METHODOLOGY

The data collection plan for the testing of devices consisted of selection of test sites, determination of measures of effectiveness (MOE), data collection procedures, and statistical tests. Each activity is described.

Selection of Test Sites

The cities selected for testing of countermeasures included Detroit, Lansing, and Grand Rapids, Michigan; Dallas and Austin, Texas; and Washington, D.C. The 32 sites selected for countermeasure testing had conditions that could potentially be improved by the device. Several general criteria and inputs were used in the initial site selection. Each device was intended to be tested in at least two of the selected cities. A list of the criteria used to select sites for each device is given in Table 1.

Selection of MOE Values

The ultimate goal of the selected countermeasures was to improve RTOR safety and reduce RTOR-pedestrian accidents. However, accident data are a poor MOE for use in testing such devices. There are three reasons for this: First, RTOR accidents are extremely rare events at any given location. To have an adequate sample of RTOR accidents before and after countermeasure installation, it may be necessary to install countermeasures at thousands of locations and then wait several years for the after-accident data. Second, RTOR-related accidents are often difficult, if not impossible, to identify from the accident report form. Finally, many devices will result in small or subtle changes in the behavior of pedestrians or motorists, or both. The detection of such changes may be possible only through the use of conflicts or other operational MOE values.

To date, no proven operational MOE has been validated as a "surrogate" or substitute for RTOR-pedestrian accidents. However, the alternatives being tested are designed to reduce or change certain types of pedestrian or motorist behavior that are contributory causes of accidents. A device that significantly reduces motorist violations of RTOR or reduces near-accidents between motorists and pedestrians at a site may be considered to have a high likelihood of improving pedestrian safety.

The specific types of conflicts and events used as MOE values were vehicle hesitation, vehicle swerve, pedestrian hesitation, pedestrian run, and interaction between a right-turning vehicle and a pedestrian. In addition to these events, RTOR violations and RTOR conflicts with cross-street vehicles were also collected for additional countermeasure evaluation. Other information collected included pedestrian volume in each crosswalk (near and far), total right-turn volume, and RTOR volume.

All of these measures were collected separately for the red signal phase and the green (plus amber) phase. This was thought to be essential because a device may significantly reduce RTOR conflicts but may also cause a corresponding increase to right-

TABLE 1 Criteria Used to Select Test Sites for Countermeasures

Counter-measure	Description	Site Criteria
1	Red ball NTOR sign	Full RTOR prohibition currently exists
		Moderate to high pedestrian volumes
		Moderate to high right-turn volumes
		High violations of the RTOR prohibition
		Considerable amount of visual clutter from other signs, traffic control devices, and development near the intersection
2	Larger NO TURN ON RED sign	Full RTOR prohibition currently exists
		Moderate to high pedestrian volumes
		Moderate to high right-turn volumes
		Moderate to high violations of existing RTOR prohibition
		NTOR sign is located near the signal on the far side of the street, where the cross street is wide (approximately four lanes or more)
3	NTOR WHEN PEDESTRIANS ARE PRESENT sign	Partial or full NTOR prohibition currently exists
		Fluctuating pedestrian volumes throughout the day, such as in the CBD or near a school
		High violation of the NTOR prohibition when the prohibition is not warranted (i.e., pedestrians and cross traffic not present)
		Adequate sight distance to make a safe RTOR
4	Red ball NTOR sign with WHEN PEDESTRIANS ARE PRESENT sign	Partial or full NTOR prohibition currently exists
		Fluctuating pedestrian volumes throughout the day, such as in the CBD or near a school
		High violation of the NTOR prohibition when the prohibition is not warranted (i.e., pedestrians and cross traffic not present)
		Considerable visual clutter may exist at the approach
5	Offset stop bar	RTOR allowed at the approach
		Moderate to high right-turn and RTOR volumes
		Low to moderate pedestrian volume
		Two or more lanes in one direction on the approach
		Trucks, buses, or other traffic in the middle lanes causes a sight distance obstruction for motorists in the right-turn lane
		Streets intersecting at an angle make it difficult for those in the right-turn lane to see cross traffic
6	LOOK FOR TURNING VEHICLES pavement markings	RTOR allowed at the approach
		Moderate pedestrian volumes
		Moderate to high right-turn and RTOR volumes
		Adequate sight distance for an RTOR maneuver
		Instances of pedestrians entering the street without looking
7	Variable message NTOR blank-out sign	Condition A: Fluctuating pedestrian volume based on time of day
		Full or partial no-turn-on-red prohibition currently exists at the site
		Fluctuating pedestrian volumes that would warrant RTOR prohibitions during specified times of day (i.e., near a school or the CBD)
		Moderate to high right-turn volume
		Adequate sight distance to make a safe RTOR maneuver when conditions permit
		High violation of the NTOR prohibitions when the prohibition is not warranted
		Condition B: Protected opposing left-turn maneuver during a portion of the cycle
		Full or partial RTOR prohibition currently exists
		High right-turn volumes
		High opposing left-turn volumes in a protected movement during a portion of the cycle
		Adequate sight distance to make an RTOR maneuver
		Low pedestrian volumes

turn-on-green (RTOG) conflicts. Thus the effect of conflicts during the entire cycle was collected.

Because of the low frequency of conflicts at each site, conflict types were combined for purposes of analysis. Thus the term "conflicts" in this analysis refers to vehicle hesitations and swerves plus pedestrian hesitations and runs. Pedestrian-vehicle interactions were analyzed separately. The term "conflicts and interactions" is used to indicate cases in which the two measures were combined. The four basic forms of the conflict measures (MOEs) were expressed as RTOR conflicts, RTOR conflicts and interactions, total RTOR + RTOG conflicts, and total RTOR + RTOG conflicts and interactions. Note that the last two measures incorporate events occurring during the entire signal cycle.

Methods of Data Collection

In addition to the MOEs described, "after" information was also collected at sites where the offset stop bar was tested relative to motorist compliance with the offset stop bar.

At many of the sites, 4 hr of data were collected followed by another 4-hr data collection period several weeks later to assess the repeatability of the data and to provide an adequate sample of events (conflicts, violations, etc.). Two different data collectors were generally sent to each city to minimize data collector biases. Although data were collected for approximately 3 hr on each approach, more emphasis was placed on the times of day when pedestrian volumes were highest or when the RTOR prohibitions were in effect.

Techniques of Statistical Analysis

The Z-test for proportions was selected as the statistical test. This test is used to determine if the proportion of occurrences in one sample (before period) is significantly different from the proportion of occurrences in a second sample (after period).

In this analysis, the events are pedestrian-vehicle conflicts (and interactions) and the opportunity for an event is either a pedestrian crossing or an RTOR maneuver. The proportion of conflicts and interactions in the before period was compared with the proportion of events in the after period at each site and a Z-value was computed. At sites where the MOE was RTOR violations, the "event" was an RTOR maneuver and the "occurrences" were the total number of right turns. Then, sites with similar treatments and within the same city were grouped, and the analysis was repeated. If the calculated Z-value is greater than the critical Z-value, the difference in proportions is statistically significant.

One other consideration was whether to use control sites to determine whether any changes observed in the conflicts and interactions were caused by the experimental devices and not by external factors. The use of control or comparison sites is particularly important when conducting accident-based evaluations when several years elapse between data collection periods. However, when conducting an evaluation using conflicts or other nonaccident MOE values, the simple before-and-after experimental design is generally appropriate with a relatively short period of time (a few weeks or months) between the before and after periods (6). Therefore, for this analysis the before-and-after experimental design was used.

RESULTS

Summary tables of the Z-test for proportion results are given for several of the devices. In each case, an indication is given of the significance at the 0.05 level and at the 0.01 level using the two-tailed test. The results of testing are discussed next.

Red Ball NTOR Sign

The results of the red ball (symbolic) NTOR sign test are summarized in Table 2. The sign resulted in an overall reduction in RTOR violations (turning right on red when prohibited) from 7.6 percent (of 10,164 right turns) in the before period to 6.2 percent (of 7,615 right turns) in the after period. This is significant at the 0.01 level. However, the overall reduction in violations is due solely to the Washington, D.C., sites, which experienced a drop in RTOR violations from 8.1 to 2.9 percent after the red ball sign was installed. On the other hand, there was an increase in RTOR violations from 7.3 to 9.4 percent at the combined Detroit sites.

Pedestrian conflicts resulting from RTOR violations were too infrequent for statistical testing. Only 22 RTOR conflicts (of 770 RTOR vehicles) were observed in the before period, or 2.9 percent, compared with no conflicts (of 473 RTOR vehicles) in the after period. Similarly, only 41 RTOR conflicts plus interactions were observed in the before period (5.3 percent) and 6 in the after period (1.3 percent).

The proportion of total (RTOR + RTOG) conflicts showed significant reduction, from 2.6 to 0.8 percent, at the combined Washington, D.C., sites. This reduction was attributed to the red ball NTOR sign. In Detroit, when right-turn volume was the basis of analysis, the red ball was also associated with a significant reduction in the proportion of conflicts (reduced from 10.8 to 8.6 percent). No significant reduction occurred in Detroit, however, if conflicts as a proportion of pedestrian volume were used as the basis of analysis.

The proportion of total (RTOR + RTOG) conflicts plus interactions dropped significantly for all sites combined in nearly all situations. Again, no significant reduction occurred at the four Detroit sites when pedestrian volume was used as the basis of analysis. When all six sites from the two cities were combined, a significant reduction was again observed in the proportion of conflicts. There was not a sufficient sample of RTOR conflicts with cross-street vehicles to conduct any analysis of that type of conflict.

In summary, the red ball NTOR sign was found to be effective in reducing the proportion of RTOR violations, total (RTOR + RTOG) conflicts, and total (RTOR + RTOG) conflicts plus interactions at the six sites combined. However, the sign was more effective at the two approaches in Washington, D.C., than at the four Detroit approaches. This could be the result of differences in sign placement in the two cities or site-related differences, or both.

Larger NO TURN ON RED Sign

The larger 30- x 36-in. (75- x 90-cm) NTOR sign was tested at one approach in Detroit and four approaches in Washington, D.C. At the Washington, D.C., sites, the proportion of RTOR violations decreased significantly (at the 0.01 level). However, no significant difference resulted in RTOR violations when the Detroit site was combined with the four Washington, D.C., sites. Overall, the violation rate remained constant at 3 percent, even though RTOR violations at the Washington, D.C., sites dropped from 7.1 to 2.7 percent.

Sample sizes of RTOR conflicts, RTOR conflicts plus interactions, total (RTOR + RTOG) conflicts, and RTOR conflicts with cross-street vehicles were insufficient for any valid analysis. For 2,186 right-turning vehicles and 899 pedestrians in the before period, only 35 conflicts occurred. Only 23 conflicts occurred in the after period for 3,333 right-turning vehicles.

TABLE 2 Summary of Results for the Red Ball NO TURN ON RED Sign

		Detroit (4 sites)		Washington, D.C. (2 sites)		All Combined (6 sites)	
MOE	Opportunity Measure	0.05 Level	0.01 Level	0.05 Level	0.01 Level	0.05 Level	0.01 Level
RTOR violations	Right-turn volume	B	B	A	A	A	A
RTOR-pedestrian conflicts	RTOR volume	–	–	–	–	–	–
RTOR-pedestrian conflicts plus interactions	RTOR volume	–	–	–	–	–	–
Total (RTOR + RTOG) pedestrian conflicts	Right-turn volume	A	A	A	A	A	A
	Pedestrian volume	NC	NC	A	A	A	A
Total (RTOR + RTOG) pedestrian conflicts plus interactions	Right-turn volume	A	A	A	A	A	A
	Pedestrian volume	NC	NC	A	A	A	A
RTOR vehicle conflicts	RTOR volume	–	–	–	–	–	–

Note: A = significant difference in favor of after (experimental) condition; B = significant difference in favor of before (base) condition; NC = no significant difference between before and after conditions; and dashes = insufficient sample size.

The proportion of total conflicts plus interactions for all five sites combined was significantly reduced with the larger NTOR sign using right-turn volume as the base. No significant change occurred, however, in the proportion of total conflicts plus interactions with respect to pedestrian volume.

In summary, there was not a sufficient sample of RTOR conflicts to make any conclusive statements about the use of the larger NTOR signs. There were some indications, however, that the signs may be effective in certain situations. For example, they resulted in a significant reduction in the proportion of violations at the four combined test sites in Washington, D.C.

NTOR WHEN PEDESTRIANS ARE PRESENT Sign

This device was tested at four sites in Detroit, and the results are summarized separately for each approach in Table 3. The supplemental WHEN PEDESTRIANS ARE PRESENT sign was used to replace either a full prohibition or a time-related prohibition (i.e., 7 a.m. to 7 p.m.). Thus the before data were collected when an RTOR prohibition was in effect. These data were then compared with data collected when the NTOR WHEN PEDESTRIANS ARE PRESENT sign, which allows an RTOR after a motorist yields to pedestrians and other motorists, was in place.

Because this device changed RTOR from a prohibited to an allowed movement (after yielding to pedestrians), it was expected to cause an increase in RTOR maneuvers without, it was hoped, causing an increase in RTOR-pedestrian conflicts. As expected, RTOR maneuvers increased from 3.3 percent (270 illegal RTOR maneuvers for 8,172 right-turning vehicles) in the before period to 5.6 percent in the after period. However, these RTOR maneuvers in the after period were legal if the motorist made a full stop and yielded to pedestrians and cross-street vehicles before making an RTOR. The increase in proportion of RTOR maneuvers was significant at the 0.01 level, which indicates a reduction in unnecessary vehicle delay in many cases.

A total of 32 RTOR-pedestrian conflicts occurred in the before period, which was 11.9 percent of the 270 RTOR maneuvers for all sites combined. This compared with no RTOR-pedestrian conflicts for the 256 RTOR maneuvers in the after period. Even though the proportion of RTOR-pedestrian conflicts dropped from 11.9 to 0 percent, the sample of conflicts was too small to be considered statistically significant. Similarly, RTOR-pedestrian conflicts plus interactions dropped from 17.8 percent (48 of 270) in the before period to only 0.3 percent (1 of 331) in the after period. The sample was too small for statistical testing.

An analysis conducted at the four approaches individually revealed inconsistent results. This sign was most effective at the sites with low right-turn volumes and appeared less effective at the sites with high right-turn volumes. Perhaps this is because the high turning demand resulted in less willingness of motorists to yield to pedestrians, particularly because RTOR was allowed in the after period.

Red Ball NTOR WHEN PEDESTRIANS ARE PRESENT Sign

The red ball (symbolic) NO TURN ON RED sign was tested in conjunction with the WHEN PEDESTRIANS ARE PRESENT message at one approach in Austin, two approaches in Dallas, and one approach in Washington, D.C. The Austin approach differed from the other three approaches in several ways, including higher right-turn volumes. Thus it was separated from the other three approaches for purposes of analysis.

The experimental device allows an RTOR after yielding to pedestrians, whereas RTOR was prohibited in the before period. Thus the device was expected to increase RTOR maneuvers without, it was hoped, increasing conflicts. As expected, RTOR maneuvers increased from 5.7 to 17.4 percent at the three sites combined (significant at the 0.01 level). The biggest increase in RTOR maneuvers occurred at Approach 3 (from 7 to 40.5 percent). Increases in the proportion of RTOR maneuvers were significant at the 0.05 level at Approach 1 and at the 0.01 level at the other two sites combined. This indicates a probable reduction in delay for right-turning motorists.

The number of RTOR-pedestrian conflicts and interactions was insufficient for statistical testing. The proportion of pedestrians involved in total (RTOR + RTOG) pedestrian conflicts was found to be reduced at Approach 1 from 6.7 percent in the before period (72 conflicts for 1,074 crossing pedestrians) to 3.2 percent in the after period (69 conflicts for 2,155 pedestrians). This was a significant reduction at the 0.01 level. Insufficient samples of conflicts were observed at the other three approaches.

A similar result was also found regarding the proportion of pedestrians involved in total (RTOR + RTOG) pedestrian conflicts plus interactions. At Approach 1, the proportion of these events dropped from 14.2 percent (152 events for 1,074 pedestrians) to 5.5 percent (118 for 2,155 pedestrians), which results in a Z-value of 8.39 (significant at the 0.01 level). Insufficient samples again prevented formal analysis at the other three approaches. Because of intersection geometrics at the Austin and Washington, D.C., approaches, there was no cross-street traffic. There was noted, however, a problem in reading the WHEN PEDESTRIANS ARE PRESENT legend in some cases. At the Austin approach, the sign was located on an overhead mast arm on the far side of the intersection adjacent to the signal face. At the Dallas approaches, the sign was mounted on a signal pole on the far side. At this distance the 10- x 24-in. (25- x 60-cm) sign, which has 2-in. (5-cm) letters, was difficult for motorists to read. The observers noted that some motorists reacted conser-

TABLE 3 Summary of Results for the NTOR WHEN PEDESTRIANS ARE PRESENT Sign

		Site 1 (Detroit)		Site 2 (Detroit)		Site 3 (Detroit)		Site 4 (Detroit)	
MOE	Opportunity Measure	0.05 Level	0.01 Level	0.05 Level	0.01 Level	0.05 Level	0.01 Level	0.05 Level	0.01 Level
RTOR maneuvers	RTOR volume	B	B	B	B	–	–	–	–
RTOR-pedestrian conflicts	RTOR volume	–	–	–	–	–	–	–	–
RTOR-pedestrian conflicts plus interactions	RTOR volume	–	–	–	–	–	–	–	–
Total (RTOR + RTOG) pedestrian conflicts	RTOR volume	B	NC	B	B	A	A	A	A
Total (RTOR + RTOG) pedestrian conflicts plus interactions	Right-turn volume	NC	NC	B	B	A	A	A	A

Note: A = significant difference in favor of after (experimental) condition; B = significant difference in favor of before (base) condition; NC = no significant difference between before and after conditions; and dashes = insufficient sample size.

vatively and did not make an RTOR maneuver. This was particularly true at the Austin approach, which was a three-legged intersection with no cross-street traffic to inhibit an RTOR. The Detroit signs were, however, located on the near side of the intersection at the corner, which makes them much easier for the right-turning motorist to read.

In summary, the red ball NTOR WHEN PEDESTRIANS ARE PRESENT sign resulted in an increase in RTOR maneuvers at all four sites, as intended. Although RTOR-pedestrian conflicts were too infrequent for statistical testing, a significant reduction resulted in the proportion of total pedestrian conflicts at one of the sites that had a high right-turn volume and high pedestrian volume. Thus, at this site, motorist turning delay was reduced and the proportion of pedestrian conflicts was also reduced, which was a desirable result. However, because of the size of the legend, the location of the sign is an important consideration.

Offset Stop Bar

The offset stop bar was tested at two approaches in Dallas and one in Washington, D.C. Samples of RTOR conflicts and interactions were insufficient for conducting any statistical tests. Only 11 RTOR conflicts plus interactions occurred for the 3,808 RTOR vehicles, or only 0.3 percent at the three approaches combined.

For the site in Washington, D.C., the proportion of total (RTOR + RTOG) pedestrian conflicts was 3.5 percent in the before period (132 conflicts for 3,756 pedestrians) and 3.2 percent in the after period (263 conflicts for 8,177 pedestrians). This represents no significant change. An insufficient sample of pedestrian conflicts was obtained at the Dallas approaches for any statistical testing.

The proportion of total (RTOR + RTOG) pedestrian conflicts plus interactions was not significantly changed at the Washington, D.C., approach. The proportion of pedestrians involved in a conflict or interaction dropped only from 5 percent in the before period to 4.7 percent in the after period. The two Dallas sites again had an insufficient sample of events for any statistical testing.

In terms of RTOR conflicts with cross-street traffic, 79 conflicts were observed in the before period, or 4.6 percent, compared with only 0.6 percent in the after period. This is a significant reduction in the proportion of conflicts at the 0.01 level of confidence.

A separate analysis was conducted to determine how motorists reacted to the offset stop bar and to assist in determining the effect on RTOR stopping characteristics. Stopping location data were collected relative to the RTOR vehicle and for vehicles in the middle (offset stop bar) lanes during the after period. Information was collected to see if the RTOR vehicle (a) stopped at or behind the stop bar, (b) stopped over or past the stop bar, or (c) did not make a full stop. At the same time, conditions in the middle lanes were examined to see if (a) no vehicles were present, (b) vehicles stopped at or behind the offset stop bar, or (c) vehicles stopped past the offset stop bar. A summary of this information is given in Table 4.

Stopping characteristics data were collected for 1,184 RTOR vehicles at the three offset stop bar sites, a majority of which were at the two Dallas sites. Of 1,184 RTOR vehicles, 22.6 percent came to a full stop behind the stop bar, 38.7 percent came to a full stop past the stop bar (61.3 percent full stop), and 38.7 percent came to a rolling stop or did not stop before making the RTOR. This compares with 56.9 percent of the motorists making a rolling or no stop at 29 RTOR-allowed approaches for which RTOR stopping characteristics were analyzed in an earlier portion of this study (1). Although 38.7 percent of the RTOR vehicles stopped past the stop bar, this percentage increased to 51.6 when vehicles in the middle lanes stopped past the offset stop bar and was somewhat lower (35.6 percent) when vehicles in the middle lanes stopped behind the offset stop bar. Whereas 22.6 percent of RTOR vehicles stopped behind the stop bar, this percentage was higher when no vehicles were in the middle lanes or the vehicles in the middle lanes stopped behind the offset stop bar, and was lower when vehicles in the middle lanes stopped past the offset stop bar.

Overall, 68.6 percent of the motorists in the middle lanes stopped behind the offset stop bar, and 31.4 percent stopped past the stop bar. This percentage varied from site to site. At one site in Dallas, 81.4 percent of the vehicles in the middle lanes stopped behind the offset stop bar, but at the other Dallas site 56.4 percent stopped behind the offset stop bar. The overall percentage of rolling or no stop RTOR vehicles remained relatively unchanged regardless of the presence and location of vehicles in the middle lanes (behind or past the offset stop bar).

In summary, conflict data for the offset stop bar revealed a significant reduction in conflicts with cross-street vehicles at all sites combined. At the one Washington, D.C., approach, no significant change occurred in the proportion of pedestrian conflicts or interactions. In terms of stopping characteristics, the offset stop bar in the middle lane or lanes was related to a higher proportion of RTOR vehicles making a full stop behind the stop bar. More testing would be desirable to verify the overall effects of the offset stop bar for various site characteristics.

TABLE 4 Summary of Stopping Characteristic Data for the Offset Stop Bar

	Vehicles in Middle Lanes			
RTOR Vehicles	No. of Vehicles (percentage)	Stop at or Behind Offset Stop Bar (percentage)	Stop Past Offset Stop Bar (percentage)	Total (percentage)
Stop at or behind the stop bar	52 (31.0)	181 (26.5)	28 (9.0)	268 (22.6)
Stop past the stop bar	54 (28.4)	243 (35.6)	161 (51.6)	458 (38.7)
Rolling or no stop	77 (40.5)	258 (37.8)	123 (39.4)	458 (38.7)
Total	190 (16.0)	682 (57.6)	312 (26.3)	1,184 (100.0)

Note: The location of the vehicle behind or past the stop bar was based on the position of the right front wheel.

TABLE 5 Summary of Results for the LOOK FOR TURNING VEHICLES Pavement Markings

		Detroit (4 Sites)		Dallas (2 Sites)		Austin (2 Sites)		All Combined (8 Sites)	
Conflict Measure	Opportunity Measure	0.05 Level	0.01 Level	0.05 Level	0.01 Level	0.05 Level	0.01 Level	0.05 Level	0.01 Level
RTOR-pedestrian conflicts	RTOR volume	–	–	–	–	–	–	A	A
RTOR-pedestrian conflicts plus interactions	RTOR volume	–	–	–	–	A	A	A	A
Total (RTOR + RTOG) pedestrian conflicts	Right-turn volume	A	A	–	–	NC	NC	A	A
	Pedestrian volume	A	A	–	–	A	A	A	NC
Total (RTOR + RTOG) pedestrian conflicts	Right-turn volume	A	A	B	B	A	NC	A	A
plus interactions	Pedestrian volume	NC	NC	B	B	A	A	A	NC

Note: A = significant difference in favor of after (experimental) condition; B = significant difference in favor of before (base) condition; NC = no significant difference between before and after conditions; and dashes = insufficient sample size.

LOOK FOR TURNING VEHICLES Pavement Marking

A summary of the results of the LOOK FOR TURNING VEHICLES pavement marking is given in Table 5. This device was tested on eight approaches in Detroit, Austin, and Dallas. The proportion of RTOR-pedestrian conflicts was significantly reduced (0.01 level) for all eight approaches combined. The proportion of RTOR conflicts plus interactions was also significantly reduced in Austin and for all sites combined after the markings were applied (from 9.7 to 2.6 percent).

The proportion of total conflicts was also significantly lower (0.01 level) for the Detroit approaches and all approaches combined as a result of the markings. Overall conflicts (per right-turn volume) dropped from 5.5 percent (408 of 7,454 vehicles) to 4.2 percent (278 of 6,563 vehicles). A similar reduction in the proportion of conflicts with respect to pedestrian volume was observed at the two Austin sites after the pavement markings were installed (at the 0.01 level).

Results based on total (RTOR + RTOG) conflicts plus interactions were somewhat more varied. Significant reductions in the proportion of conflicts and interactions were found in Austin and Detroit (0.05 level or better) with a significant increase (0.01 level) in Dallas. The eight sites combined showed an improvement (significant at the 0.05 level) when the proportion of total conflicts plus interactions (with respect to right-turning vehicles) was reduced from 10.2 to 8.6 percent. While collecting the after data, the observers also noted several instances of people walking into the crosswalk while looking down, who, after reading the pavement marking, would look both ways. Although a formal analysis of this information was not conducted, these observations indicate a potential benefit of having these messages to caution pedestrians.

In summary, the LOOK FOR TURNING VEHICLES pavement marking showed an overall reduction in conflicts and interactions for RTOR vehicles and also for total (RTOR + RTOG) vehicles. However, the results were mixed because it was ineffective at the Dallas sites. One possible explanation is that there may indeed be real differences in the effectiveness of such devices depending on the area and locational characteristics. The markings do appear to be of value in reducing conflicts at some sites, as found in this analysis.

A practical consideration with this device is that it may be covered by snow in winter months and tend to wear away quickly on poor pavement surfaces, which may cause a maintenance problem. A few of the pavement markings were worn away within a few weeks after application where the pavement was poor whereas others were fully visible after 3 to 4 months.

Electronic NTOR Blank-Out Sign

The electronic NTOR blank-out sign was tested at four approaches in Lansing, Michigan, and one approach in Grand Rapids, Michigan. The four Lansing approaches were at school zones, where pedestrian activity consisted predominantly of school children who crossed the street during a limited period of time each school day. Thus very few RTOR-pedestrian conflicts occurred during either the before or after period, which prevented any formal evaluation based on pedestrian conflicts.

Regarding compliance with the NO TURN ON RED message, several interesting results were found. At one intersection in Lansing, the NTOR blank-out sign was installed on two approaches to replace standard NTOR signs (full prohibition). The analysis involved combining data at the two approaches. In the before period (with standard NTOR sign), 62 of 3,396 right-turning motorists (1.83 percent) illegally made an RTOR. During the after period with the electronic NTOR sign illuminated only one motorist out of 622 (0.2 percent) violated the sign. A different analysis was then made in the after period of the RTOR maneuvers that occurred during the blank-out period (RTOR allowed) versus the NTOR illuminated period (RTOR prohibited). As expected, 16.8 percent, or 298 of 1,767 right-turning motorists, made an RTOR when allowed compared with only 0.2 percent (1 of 622) when prohibited. This illustrates that the electronic sign effectively allowed RTOR maneuvers when justified (i.e., few or no pedestrians crossing) and virtually eliminated RTOR maneuvers during periods when children were present.

At the second intersection in Lansing, electronic NTOR blank-out signs already were operational on two separate approaches. Thus no data were available for the before period. The two approaches were combined for analysis, and RTOR maneuvers were compared for the blank-out period (RTOR allowed) and the illuminated (RTOR prohibited) time of day. During the blank-out periods, 28 percent (194 of 672) of right-turning vehicles made an RTOR maneuver. When the sign was illuminated NO TURN ON RED, 5.1 percent (19 of 369) of motorists made an illegal RTOR maneuver. This was a significant reduction in RTOR maneuvers, even though 19 motorists made an illegal RTOR maneuver while the sign was illuminated. However, none of these illegal maneuvers resulted in a pedestrian conflict or interaction.

The third intersection with the NTOR blank-out sign consisted of only one approach in Grand Rapids, Michigan. The electronic sign was tested under three separate operations:

- Operation 1: The sign showed an illuminated NO TURN ON RED message for only a 17-sec interval of each cycle during an opposing left-turn phase that conflicts with the RTOR maneuver.

• Operation 2: The sign was illuminated NO TURN ON RED continuously, 24 hr per day.

• Operation 3: The sign was illuminated NO TURN ON RED during the entire red interval for the approach (60 sec of NTOR for the 90-sec off-peak cycle lengths and 70 sec of NTOR for the 105-sec peak-period cycle lengths).

The opposing approach was used as a comparison because it was posted with a standard NO TURN ON RED sign.

A summary was prepared of the RTOR violations for each of the conditions listed including the comparison site (Table 6). Between 13 and 30 hr of data were collected for each condition. During Operation 1 (NTOR illuminated only 17 sec each phase) and Operation 2 (NTOR illuminated continuously), 1.9 percent of motorists committed an RTOR violation. When the sign was illuminated during the entire red phase (Operation 3), a 2.9 percent violation rate resulted, which was comparable with the 2.6 percent violation rate at the comparison site.

The proportion of violations (1.9 percent) for Operations 1 and 2 was significantly lower than that of either the comparison site or Operation 3. However, note that the right-turn volume at the test site was nearly constant at 400 to 434 for various test periods, whereas the comparison site had only 59 right turns per hour. Thus the RTOR violations at the comparison site might be expected to differ if right-turn volume increased to 400 per hour. The pedestrian conflicts and interactions for all conditions were negligible primarily because of low pedestrian volumes.

In summary, the electronic NTOR blank-out signs were found to be generally effective in terms of a low RTOR violation rate (less than 2 percent in most cases). The effectiveness of this electronic device compared with the standard NTOR sign appears to be better in some instances, although differences are slight. However, the variable message device also results in increased use of RTOR during periods when RTOR is appropriate and thus reduces unnecessary motorist right-turn delay. The use of the device was associated with a negligible number of RTOR-pedestrian conflicts.

The blank-out device, however, eliminates the confusion of motorists about when a prohibition is, indeed, in effect. (Legends that state NTOR 7:30 AM TO 9:30 AM, or NTOR SCHOOL DAYS ONLY, or NTOR WHEN PEDESTRIANS ARE PRESENT often create such confusion.) One of the devices at a school site in Lansing was equipped with an actuation device that could only be used by an authorized person, such as the crossing guard. When activated, the device would display the NTOR prohibition for a preset time period (45 to 90 min when children were present) and would automatically shut off.

FINDINGS AND CONCLUSIONS

The red ball NO TURN ON RED sign was found overall to be more effective than the standard black and white NTOR sign in terms of RTOR violations and pedestrian conflicts. However, the overall reduction was due solely to the Washington, D.C., sites. The red ball sign was less effective at the Detroit sites, where signs were not mounted near the signal. The red ball sign appears to be more conspicuous to motorists than the current sign because of its distinctive red color in the center. It is recommended that the red ball NTOR sign be added to the Manual on Uniform Traffic Control Devices (MUTCD) as an alternative to or replacement for the existing sign. Subject to laboratory testing or additional field testing, or both, consideration should be given to eliminating the current NTOR sign from the MUTCD.

The larger, 30- x 36-in. (75- x 90-cm), NO TURN ON RED sign reduced the proportion of violations at most of the test sites in one city and reduced total conflicts in some situations. It is recommended that the larger sign be considered by agencies for use at sites where the sign is currently hard to read, such as far-side post mounting when overhead mounting is not feasible.

The NO TURN ON RED sign with the supplementary WHEN PEDESTRIANS ARE PRESENT message was effective at sites where right-turning vehicle volumes were low or moderate but less effective when RTOR volumes were high. It was effective in increasing RTOR maneuvers (as desired) during periods when volume was light. It is recommended that the supplemental message WHEN PEDESTRIANS ARE PRESENT be added to the MUTCD as an accepted message that may be used with a NTOR sign when right-turn volume is light to moderate and pedestrian volumes are light or occur primarily during intermittent periods (i.e., in school zones) (7). However, consideration should be given to use of a large, readable legend consistent with sign location.

The red ball NTOR sign in conjunction with the WHEN PEDESTRIANS ARE PRESENT message reduced total pedestrian conflicts in one instance and increased RTOR usage as desired. It should be added to the MUTCD as an optional sign.

The offset stop bar was tested to provide better sight distance to the left for RTOR motorists. It was effective overall in reducing RTOR conflicts with cross-street traffic and also resulted in more RTOR vehicles making a full stop behind the stop bar. The offset stop bar is a recommended counter-

TABLE 6 Summary of RTOR Violations Resulting from Electronic NTOR Blank-Out Sign

Operation No.	Type of RTOR Prohibition	Total Data Collection Time (hr)	Total Right-Turn Volume (No./hr)	RTOR Volume		Percentage RTOR		No. of Pedestrian Conflicts plus Interactions	
				Legal	Illegal	Legal	Illegal	RTOR	RTOG
1 (test site 3)	Illuminated NTOR: 17 sec/cycle during opposing left-turn phase	30.3	12,241 (404)	3,950	227	32.3	1.9	3	9
2 (test site 3)	Continuous illumination of NTOR	14.8	6,372 (431)		118		1.9	0	3
3 (test site 3)	Illumination of NTOR during full red phase	13.3	5,769 (434)		170		2.9	0	2
Comparison site	Standard NTOR sign	16.5	977 (59)		25		2.6	0	2

measure for consideration at RTOR-allowed sites that have two or more lanes on an approach and heavy truck or bus traffic or unusual geometrics.

The LOOK FOR TURNING VEHICLES pavement marking was effective in reducing RTOR-pedestrian conflicts and total pedestrian conflicts at several sites and was ineffective at others, depending on the city and specific site characteristics. Such markings should be considered as possible treatments only at sites with particular problems with pedestrian accidents or conflicts with right-turning vehicles. Because the markings may wear away quickly, the use of cold plastic should be considered to avoid constant maintenance.

The electronic NO TURN ON RED blank-out sign was found to be slightly better than the standard NO TURN ON RED sign in terms of violations. The device was also effective in increasing RTOR maneuvers when RTOR was appropriate (i.e., blank-out mode) and thus reduced unnecessary vehicle delay. Although this electronic device is more expensive than signs and markings it may be justified (a) in situations in which pedestrian protection is critical during certain periods (such as school zones) or (b) during a portion of the signal cycle when a separate, opposing, left-turn phase may conflict with an unsuspecting RTOR motorist.

REFERENCES

1. C.V. Zegeer and M.J. Cynecki. Methods of Increasing Pedestrian Safety at Right-Turn-On-Red Intersections. Final Report. Goodell-Grivas, Inc., Southfield, Mich.; FHWA, U.S. Department of Transportation, March 1985.
2. M.R. Parker, Jr. The Impact of General Permissive Right- and Left-Turn-On-Red Legislation in Virginia. VHTRC 74-R7. Virginia Highway and Transportation Research Council, Charlottesville, Sept. 1978.
3. H.W. McGee. Guidelines for Prohibiting Right-Turn-On-Red at Signalized Intersections. Transportation Engineering, Vol. 48, No. 1, Jan. 1978.
4. D.F. Preusser, W.A. Leaf, K.B. Debartlo, and R.D. Blomberg. The Effects of Right-Turn-On-Red on Pedestrian and Bicycle Accidents. Dunlap and Associates, Inc., Dayien, Conn., Oct. 1981.
5. ITE Committee 4A-17. Guidelines for Prohibition of Turns on Red. ITE Journal, Feb. 1984, pp. 17-19.
6. D. Perkins. Highway Safety Evaluation--Procedural Guide. Goodell-Grivas, Inc., Southfield, Mich.; FHWA, U.S. Department of Transportation, March 1981.
7. Manual on Uniform Traffic Control Devices for Streets and Highways. FHWA, U.S. Department of Transportation, 1978.

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