Determination of Motorist Violations and Pedestrian-Related Countermeasures Related to Right-Turn-on-Red

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ABSTRACT

The adoption of the permissive right-turn-on-red (RTOR) rule in the United States (except for New York City) has resulted in possible problems with respect to motorists failing to make a full stop before turning right on red. Also, the rate of motorist violations to the NO TURN ON RED sign was also raised as a related problem. The purpose of this study was to determine these violation rates relative to RTOR and to determine the resulting pedestrian-related conflicts associated with RTOR maneuvers. Based on the collection of observational data for more than 67,000 drivers at 110 intersections in Washington, D.C.; Detroit, Michigan; and Dallas and Austin, Texas, 3.7 percent of all right-turning motorists at RTOR-prohibited intersections violate the RTOR prohibition signs. However, of those motorists given an opportunity to commit an RTOR violation, about 21 percent violate the NO TURN ON RED sign. Although 23.4 percent of RTOR violations result in a conflict with another vehicle or pedestrian, only about 1 out of every 100 total right-turn vehicles is involved in an RTOR conflict. In terms of stopping characteristics at RTOR-allowed sites, 56.9 percent of motorists fail to make a full stop before turning right on red. An analysis of specific data-collection sites resulted in a list of locational factors associated with high and low violation rates. From this analysis a list of 30 candidate countermeasures was developed for possible use relative to RTOR.

The recent adoption of the Western Rule in the United States relative to right-turn-on-red (RTOR), except for New York City, has resulted in the right of motorists to turn right on a red signal (except when otherwise signed) after stopping and yielding to pedestrians and motorists. However, two of the reported problems of the generally permissive RTOR rule involve motorists:

1. Turning right on red at RTOR-prohibited locations (i.e., NO TURN ON RED signs exist), and
2. Turning right on red (where permitted) without stopping.

It has been speculated that one of the causes of violations of RTOR prohibitions is the carry-over effect to motorists because of the current permissive RTOR rule that causes them to expect to be able to turn right on red at all intersections. One confounding problem is that the NO TURN ON RED (NTOR) sign is not always placed in the same position, and it may not be noticeable to drivers even when the sign is placed in accordance with Manual on Uniform Traffic Control Devices (MUTCD) standards (1). Other problems involve the lack of police enforcement of RTOR prohibition in many areas. The current MUTCD warrants for an NTOR sign have led to the high use of RTOR prohibitions in some cities and little or no use in other cities. Many believe that RTOR is not hazardous, and therefore prohibitions are rarely if ever needed. Others view RTOR as a detriment to safety in that it should never have been implemented.

The other compliance problem with RTOR relates to RTOR vehicles that fail to come to a full stop before turning right on red where RTOR is allowed. Previous studies have indicated that between 3 and 65 percent of vehicles commit such RTOR violations (2,3). However, only about 1 to 3 percent of RTOR violations (i.e., failing to stop) resulted in an unsafe act or hazardous situation (3).

With evidence of these two types of RTOR violations, a need exists to determine the current status of motorist compliance with RTOR prohibition. Therefore, the purpose of this study was to

1. Conduct observational studies at signalized intersections in several cities to determine current motorist compliance with RTOR prohibition (NTOR signs) and the requirement to make a full stop before turning right on red (where RTOR is permitted);
2. Collect traffic, geometric, and other physical site characteristics and determine what site factors are associated with high and low rates of RTOR violations; and
3. Develop a list of countermeasures for increasing compliance or reducing hazards or both related to RTOR.

MOTORIST COMPLIANCE WITH RTOR LAWS

One of the objections to the generally permissive RTOR regulation is that motorists frequently do not stop before turning on red. Such concerns have recently been expressed in several studies (2-5). An assessment of motorist compliance with stopping is presented in the following section, followed by a discussion of motorist violation of turning on red where the maneuver is prohibited.

Compliance Where RTOR is Permitted

The generally permissive RTOR rule requires that motorists must come to a full stop and yield to pedestrians and other traffic in the intersection before turning on red. There have been several examinations of motorist compliance and violations to the RTOR law. A 1983 study (6) found that overall, 40 percent of the drivers who turned on red failed to come to a stop before turning. Violation rates per site ranged from 38 to 71 percent of RTOR vehicles. Under the sign-permissive rule in Virginia, Parker et al. (7) found that 9 percent of the RTOR motorists at 15 approaches did not come to a full stop before turning. A study conducted at 11 sites in Providence, Rhode Island, found that 65 percent of the motorists did not stop (8). At 12 locations in Springfield, Massachusetts, only 28 percent of the RTOR motorists did not come to a full stop (8). The low violation rate in Springfield was attributed to the newness of the RTOR maneuver and the sign reminding motorists to stop. Baumgaertner (3) collected compliance data at 13 approaches in Maryland and also found that the noncompliance rate under the sign-permissive rule was 64.4 percent, which compares closely with the Providence data.

RTOR violation data were collected for generally permissive RTOR in two studies in which the general rule had only been adopted for 1 year (2,6). At seven approaches in North Carolina, Parker et al. (7) found that 2.0 percent of the RTOR motorists did not stop. However, after generally permissive legislation was enacted in Virginia, Parker (2) found that 11.5 percent of the RTOR motorists violated the law. It is important to note that the violation rate varied considerably with 48 percent of the violations reported at two approaches.

A high violation rate creates a law enforcement problem and may lead to a serious safety problem. In their studies, Baumgaertner (3) and Parker (2) also recorded the number of unsafe turns where the RTOR motorists did not stop or yield to other traffic in the immediate vicinity of the intersection. In both studies less than 2 percent of the motorists made an unsafe turn. Additional studies of motorist compliance are needed periodically to examine trends over time and to identify unsafe approaches so that appropriate countermeasures can be applied.

The magnitude of the RTOR violation problem can be put into perspective by comparing it with motorist compliance at stop sign locations. In a Chicago study, 53 to 76 percent of all drivers failed to come to a complete stop at stop signs. However, only 5 to 10 percent of all vehicles traveling in excess of 5 mph (8 km/h) violated the stop sign (9). A 1976 study by Baubien (10) was conducted in Troy, Michigan, to determine whether stop signs were effective for speed control in residential areas. At the three locations full stops ranged from 6 to 51 percent of vehicles, rolling stops ranged from 34 to 54 percent, and no-stops ranged from 15 to 47 percent (10). Based on these data, the violation rate involving stop signs appears to be considerably higher than the RTOR noncompliance rate.

A 1978 study observed motorist obedience to the stop signs in Barton, Springfield, and Providence. The percentage of vehicle violations (not stopping) ranged from 31 to 39 percent. Of those vehicles not forced to stop by cross-street traffic, the percentage of violations (nonstopping vehicles) ranged from 35.2 to 71.2 percent (8).

Violations Where RTOR is Prohibited

Another major concern is whether motorists are violating the law by turning right on red at locations where the maneuver is prohibited. There is evidence that violations do occur. The most recent study was conducted in New Jersey in 1983, and it was noted that 6 percent of right-turn vehicles turned on red (at five intersections) where RTOR was prohibited (6).

Benke and Ries (11) collected violation data at 11 sites where RTOR maneuvers were prohibited under sign-permissive and generally permissive rules and found that the violation rates were 1.23 and 9.56 percent, respectively (i.e., 1.23 percent of the motorists made an illegal RTOR maneuver). The authors attributed the high violation rate, which occurred at 4 of the 11 sites, to poor visibility of the sign resulting from poor sign placement and a busy signing environment at one location. In Indiana Mamlouk (12) found that 1.4 percent of the motorists made an illegal RTOR maneuver under the sign-permissive rule. It was also reported that the violation rate varied considerably, with one site having an 18 percent violation rate. At that location sign placement made it difficult for motorists to see the traffic control device.

METHODOLOGY

Data were collected to investigate two problems associated with RTOR: (a) to determine if RTOR prohibitions are being obeyed, and (b) to determine if motorists are coming to a complete stop before making an RTOR maneuver where RTOR is permitted. Each of these problems required separate data-collection plans and procedures, as discussed in the following sections.

Data-Collection Plan for Violations of RTOR-Prohibited Locations

Selection of Cities for Data Collection

One of the factors that could have a major impact on RTOR compliance is the recent history of RTOR in the area, because this could influence the level of motorist knowledge and understanding of RTOR and RTOR prohibition. For example, motorists in cities that have had the Western Rule for many years (e.g., Los Angeles) may respond differently to RTOR prohibition than motorists in eastern cities that have used the Eastern Rule until recently (e.g., Washington, D.C.). Other factors such as level of police enforcement of RTOR, area characteristics, and local driver characteristics may also affect the level of compliance and vary from city to city or state to state, although such factors are difficult or impossible to quantify.

To allow for collecting data for a variety of conditions, three U.S. metropolitan areas were selected:

1. One city in the western United States that has had the Western Rule (RTOR permissive law) in effect for many years,
2. One city in the eastern United States that has only recently adopted the Western Rule (within 4 or 5 years), and
3. One city in a neutral part of the country such as the Midwest.

After discussions with the FHWA and numerous cities, it was decided to use Washington, D.C., to represent the city that until recently had the Eastern Rule. The cities of Dallas and Austin, Texas, were selected to represent cities with the Western Rule, and Detroit, Michigan, was selected from the

Midwest. Washington, D.C., currently prohibits RTOR (for either part of the day or all day) at approximately 70 percent of its intersections. RTOR is prohibited at only a small percentage of intersections in Dallas and Austin, whereas RTOR prohibition is used at an estimated 10 to 20 percent of signalized intersections in the Detroit area.

Selection of Data-Collection Sites

Sites were selected to provide a variety of geometric, volume, and other conditions throughout the city. One of the site selection criteria was moderate to high levels of pedestrian volume. However, some sites with low pedestrian volumes were selected that exhibited unusual geometrics. Also, intersections that have two or more approaches that prohibit RTOR were selected in many instances to facilitate data collection.

To select the sites and approaches, a list of sites with RTOR prohibition was obtained from each city. The sites were field reviewed by the project engineers before data collection. During this review basic site information was obtained and observation points and data-collection time periods were selected. Violation data were collected for a total of 110 approaches to provide a variety of site characteristics.

Development of Data-Collection Forms and Procedures

Data-collection forms and procedures were developed to assist observers in obtaining accurate and consistent data. Two basic types of data were collected: site data and violation data. Site data collected included all traffic control devices (signs, signals, and pavement markings), intersection geometrics, posted speed limits, sight distance for the right-turn vehicle, and pertinent signal data.

The reverse side of the form was used for the condition diagram, and observers were instructed to draw a detailed site diagram with street widths, location of pavement markings, signs and signals, special turn lanes, intersection geometry, type of development on each corner, location of on-street parking (if any), and other physical features. Observation data were collected in 10-min intervals on form 1 and included the following items:

1. Start time and end time of the data-collection period (military time).
2. Approach (northbound, eastbound, and so forth).
3. The number of right-turn-on-green (RTOG) vehicles. RTOG vehicles were categorized into arrive on green, arrive on red (RTOR opportunity), and arrive on red (no RTOR opportunity).
4. RTOR maneuvers, which were categorized into no conflict, conflict with traffic, and conflict with pedestrians. Pedestrian conflicts were recorded based on whether they occurred at the near or far crosswalk and the type of conflict: (a) vehicle hesitation (VH)--vehicle slows or stops to avoid hitting a pedestrian while executing an RTOR maneuver; (b) vehicle swerve (VS)--vehicle swerves to avoid hitting a crossing pedestrian; (c) pedestrian hesitation (PH)--pedestrian slows, stops, or reverses his direction of travel to avoid a collision; (d) pedestrian run (PR)--pedestrian increases his speed or runs to avoid a collision; and (e) interaction (I)--neither the vehicle nor the pedestrian reacts but the pedestrian is in a moving lane and is within 20 ft (6 m) downstream of an RTOR vehicle.
5. Pedestrian volume, where the total number of crossing pedestrians is recorded separately for the near and far crosswalks, regardless of their direction of travel or compliance with the pedestrian or traffic signal.

When two or more conflict types occurred during a single event (i.e., a vehicle hesitates and a pedestrian runs during the same RTOR event), only the most severe conflict was recorded. Only one conflict was recorded per RTOR vehicle, regardless of the number of pedestrians involved in the conflict.

A minimum of 4 hr of data was collected on each approach. Eight or more hours of data were collected on several approaches to test for data repeatability.

Data-Collection Plan for Violation Data at RTOR-Permitted Approaches

This portion of the study involved collecting violation data at RTOR-permitted sites to determine whether vehicles were making a complete stop before their RTOR maneuver. These data were later compared with stopping characteristic data for right-turn motorists at stop sign locations. The data were collected at sites within Washington, D.C.; Dallas/Austin, Texas; and Detroit, Michigan, as discussed earlier.

Selection of Data-Collection Sites

Sites selected included signalized intersections with at least two approaches that permit RTOR or intersections with at least two approaches controlled by stop signs. Initial site selection was made by selecting a list of potential test sites. Final site selection was made by reviewing candidate sites with high right-turn volume, high RTOR volume (signalized locations), and moderate to high pedestrian volumes. The sites selected were in the vicinity of the RTOR-prohibited locations used for collection of violation data relative to prohibition signs. Data were collected for 29 total approaches of signalized intersections and 28 stop sign approaches.

Development of Data-Collection Forms and Procedures

Data collected included site information and stopping characteristics (observation data). Site data were also collected as described earlier. Observation data were collected on the RTOR and stop sign stopping characteristics data form. A total of 4 hr of data were collected on each approach, or a total of 8 hr at each intersection. Data collection was alternated between two approaches with 30 min of data collected on an approach (summarized and recorded in 10-min intervals). In this manner, data were sampled from both approaches throughout the day.

Data collected on the RTOR and stop sign stopping characteristics data form included the following:

1. Intersection name, city, location, and so forth.
2. Intersection control, such as traffic signal or stop sign.
3. Time period data collection began and ended (military time).
4. Approach (northbound, eastbound, and so forth).
5. RTOG--the number of vehicles that turn right on green signal indications (for signalized approaches only).

6. RTOR vehicles--the type of stop for RTOR or stop sign right-turn vehicles, which are defined as (a) no stop--the vehicle slows only to negotiate the right turn and does not make any effort to stop; (b) rolling stop--the right-turn vehicle slows more than the no-stop condition but at no time do the wheels come to a complete stop in the vicinity of the stop bar or crosswalk; (c) full stop-voluntary--the vehicle comes to a complete stop in the vicinity of the stop bar or crosswalk but is not forced to stop by pedestrians in the crosswalk or by cross-street traffic; and (d) full stop-forced--the vehicle comes to a complete stop in the vicinity of the stop bar or crosswalk and does so because of the existence of pedestrian crosswalk activity or through traffic. (Note that this does not necessarily mean the vehicles would not have voluntarily stopped if no pedestrian or cross-traffic were present.)

7. Pedestrian volume--crossing pedestrian traffic on the near or far side crosswalk.

8. Opposing traffic--the cross traffic potentially conflicting with RTOR or right-turns at stop signs. For an approach that intersects a two-way street, only the direction of cross traffic that conflicts with the right-turn maneuver would be counted.

RESULTS

Status of Violations to RTOR Prohibition Signs

Violation data were collected at a total of 110 intersection approaches relative to vehicles illegally turning right on red. The violation rate for a group of sites may be expressed in several different ways:

1. Overall RTOR violation rate is the overall percentage of right-turn vehicles that turn right on red (i.e., total number of RTOR events at a group of sites divided by the total right-turn volume). This was a common way of expressing violations in past studies.

2. Mean RTOR violation rate is the average percentage of right-turn vehicles that turn right on red (i.e., the mean percent violations of a sample of intersection approaches). This can only be computed for a sample of two or more sites.

3. Overall RTOR violation rates per opportunity is the percentage of vehicles turning right on red of those vehicles that have an opportunity to do so. In the first two definitions (1 and 2), all right-turning vehicles are included in the denominator, regardless of whether they arrive on red, arrive on green, or had an opportunity to make an RTOR (i.e., they were the second or third car stopped in the right-turn lane, or a lack of gaps in cross-street traffic prevented them from turning right on red). This definition only includes those vehicles stopped first in line at the red light that have an adequate gap and an opportunity to turn right on red. It is really a measure of the percentage of motorists who would violate the RTOR prohibition if given the chance. This definition will result in a higher percent violation rate than the previous two definitions.

4. Mean RTOR violation rate per opportunity is the same as the previous definition, except a mean of the violation rates of the sites is used.

To illustrate the three definitions of violation rate, consider hypothetical data on three intersection approaches, A, B, and C (1 hr of data per approach) when each has NTOR signs (Table 1). From the sample data in Table 1, the overall RTOR violation rate for the three approaches is the total RTOR (18) divided by the total right turns (135), or 13.3 percent. The mean RTOR violation rate for the three approaches is the average of 6.0 percent (Approach A), 11.1 percent (Approach B), and 25.0 percent (Approach C), or 14.0 percent. This differs slightly from the 13.3 percent overall RTOR violation rate.

To compute the overall and mean RTOR violation rate per opportunity only the RTOR opportunities are used in the denominator. Thus, in the sample data in Table 1, the overall RTOR violation rate per opportunity for the three approaches is the total number of violations (18) divided by the total opportunities (60), or 30.0 percent. The mean RTOR violation rate per opportunity is computed as the average violation rate of Approach A (30.0 percent), Approach B (25.0 percent), and Approach C (33.3 percent), or 29.4 percent, which differs slightly from the 30.0 overall rate.

The actual violation rates are given in Table 2 for each of the three cities and for the overall data base. Of the 110 intersection approaches, 59

TABLE 1 Hypothetical Data on Three Intersection Approaches

Approach	Total Right Turns	RTOR Violations	RTOR Opportunities	Vehicles Turning Right on Red (%)	Vehicles Turning Right on Red That Had An Opportunity (%)
A	50	3	10	6.0	30.0
B	45	5	20	11.1	25.0
C	40	10	30	25.0	33.3
Total	135	18	60		

TABLE 2 Summary of RTOR Violations at RTOR-Prohibited Sites

City	Total Approaches	Right Turns	Total RTOR Violations	Violation Rate (%)		Total RTOR Opportunities	Violation Rate per Opportunity (%)	
				Overall	Mean		Overall	Mean
Detroit	59	33,400	1,119	3.4	4.7	5,904	19.0	22.0
Washington, D.C.	27	22,742	888	3.9	4.6	4,122	21.5	19.4
Dallas/Austin	24	11,205	493	4.4	6.9	2,288	21.5	24.6
Total	110	67,347	2,500	3.7	5.1	12,314	20.3	21.9

TABLE 3 Summary of Violations and Conflicts at RTOR-Prohibited Sites

City	Total No. of Violations	RTOR Violations Resulting in Conflicts									
		Total Conflicts		Conflicts with Traffic		Total Conflicts with Pedestrians		Pedestrian Conflicts			
								Near Crosswalk Only		Far Crosswalk Only	
		No.	Percent	No.	Percent	No.	Percent	No.	Percent	No.	Percent
Detroit	1,119	246	22.0	79	7.1	167	14.9	61	5.5	106	9.5
Washington, D.C.	888	199	22.4	28	3.2	171	19.3	44	5.0	127	14.3
Dallas/Austin	493	140	28.4	80	16.2	60	12.2	34	6.9	26	5.3
Total	2,500	585	23.4	187	7.5	398	15.9	139	5.6	259	10.4

were from Detroit, 27 from Washington, D.C., and 24 from the Dallas/Austin area. A total of 2,500 violations were observed for the 67,347 total turning vehicles, or 3.7 percent overall. The overall violation rates ranged between 3.4 percent (Detroit) and 4.4 percent (Dallas/Austin). The mean violation rate was 5.1 for all sites and ranged from 4.6 percent (Washington, D.C.) to 6.9 percent (Dallas/Austin). These numbers compare closely with the 6 percent overall violation rate found by Davis and Mullowney (6) in New Jersey at 11 sites in a 1983 study.

Other information in Table 2 relates to RTOR violation rates per opportunity. For example, of the 67,347 right turns at the 110 sites, only 12,314 (18.3 percent) had an opportunity to turn right on red. This is because many arrived and turned right on green or were not the lead vehicle stopped in the right-turn lane (could not physically make the turn on red). In a few cases no opportunity existed for a RTOR violation because of high pedestrian or cross-street traffic.

The overall RTOR violation rate per opportunity was 20.3 percent. The rate was consistent among the cities, ranging from 19.0 percent (Detroit) to 21.5 percent (Washington and Dallas/Austin). This indicates that about 1 out of every 5 motorists turns right on red when given the opportunity when it is prohibited.

One additional analysis was also conducted of the percentage of overall RTOR violations that resulted in a conflict, as summarized in Table 3. Of the 2,500 total RTOR violations at the 110 approaches, 585 (23.4 percent) resulted in some type of conflict. Of the 2,500 violations, 187 (7.5 percent) involved cross traffic, 139 (5.6 percent) involved pedestrians in the near crosswalk, and 259 (10.4 percent) involved pedestrians in the far crosswalk.

In terms of individual cities, RTOR violations in Dallas/Austin resulted in a conflict 28.4 percent of the time compared with approximately 22 percent in the other two cities. In particular, 16.2 percent of RTOR violations in Dallas/Austin resulted in a cross-traffic conflict, compared with 3.2 percent and 7.1 percent in Washington, D.C., and Detroit, respectively. However, pedestrian-related conflicts ranged from 19.3 percent of RTOR violations in Washington, D.C., compared with 14.9 percent (Detroit) and 12.2 percent (Dallas/Austin), probably because of the higher densities of pedestrians at the Washington sites.

These pedestrian conflicts occurred most frequently on the near crosswalk in Dallas/Austin (6.9 percent on the near crosswalk to 5.3 percent on the far crosswalk). However, the far crosswalks experienced more pedestrian conflicts than the near crosswalks at the sites in Washington (14.3 to 5.0 percent) and Detroit (9.5 to 5.1 percent). RTOR violations with pedestrians in the far crosswalk could be largely the result of pedestrian violations, because during a red phase pedestrians in the near crosswalk would normally have the WALK interval.

It should be remembered from the previous discussion that although 23.4 percent of all RTOR violations resulted in conflicts, only 3.7 percent of all right-turning vehicles committed an RTOR violation. Thus only 0.234 x 0.037 = 0.9 percent (less than 1 in 100) of the right-turn vehicles was involved in any kind of an RTOR-related conflict (585 RTOR-related conflicts for 67,347 total right-turning vehicles). Further, RTOR-pedestrian conflicts resulted from only 398 of 67,347 right-turning vehicles (0.59 percent), or about 6 out of every 1,000 right-turning vehicles. It should also be remembered that a majority of the sample sites were in areas with moderate to high pedestrian volumes, so these percentages of pedestrian conflicts are likely higher than would be expected for the overall sample of intersections in a city.

As discussed earlier, details were also recorded for the specific types of pedestrian conflicts resulting from each RTOR violation, as summarized in Table 4. Of the 398 resulting pedestrian conflicts, the most prevalent types were pedestrian-vehicle interactions (36.5 percent), pedestrian hesitations

TABLE 4 Summary of Types of Pedestrian Conflicts Resulting from Violations of RTOR Prohibitions

Type of Pedestrian Conflict	Conflicts					
	Near Crosswalk		Far Crosswalk		Total	
	No.	Percent	No.	Percent	No.	Percent
Vehicle hesitation	27	19.4	81	31.3	108	27.1
Vehicle swerve	2	1.5	4	1.5	6	1.5
Pedestrian hesitation	48	34.5	75	29.0	123	30.9
Pedestrian run	4	2.9	12	4.6	16	4.0
Pedestrian/vehicle interaction	58	41.7	87	33.6	145	36.5
Total	139	100.0	259	100.0	398	100.0

TABLE 5 Comparison of Pedestrian Conflicts Occurring with RTOR and RTOG

City	Total Right Turns	RTOR	RTOG	RTOR (%)	RTOR with Conflict: Cross Traffic No.	Cross Traffic Percent	Pedestrians at Near Crosswalk No.	Pedestrians at Near Crosswalk Percent	Pedestrians at Far Crosswalk No.	Pedestrians at Far Crosswalk Percent	RTOG with Conflict: Pedestrians at Near Crosswalk No.	Pedestrians at Near Crosswalk Percent	Pedestrians at Far Crosswalk No.	Pedestrians at Far Crosswalk Percent
Detroit	20,867	761	20,106	3.6	49	6.4	39	5.1	60	7.9	149	0.7	3,547	17.6
Washington, D.C.	9,000	334	8.666	3.7	5	1.5	17	5.1	57	17.1	87	1.0	2,628	30.3
Dallas/Austin	8,095	393	7,702	4.9	72	18.3	20	5.1	19	4.8	35	0.5	690	9.0
Total	37,962	1,488	36,474	3.9	126	8.5	76	5.1	136	9.1	271	0.7	6,865	18.8

(30.9 percent), and vehicle hesitations (27.1 percent). Only 16 pedestrian runs and 6 vehicle swerves were observed during the 573 hr of data collection. Vehicle hesitations were more prevalent in the far crosswalk than the near crosswalk (31.3 percent to 19.4 percent) and pedestrian-vehicle interactions were more common on the near crosswalk than on the far crosswalk (41.7 to 33.6 percent).

A comparison was also made between RTOR-related conflicts and RTOG conflicts for a sample of the data sites, as summarized in Table 5. The sample includes 37,962 right-turn vehicles, of which 1,488 (3.9 percent) illegally turned right on red and 96.1 percent turned right on green. In terms of pedestrians, 14.2 percent of RTOR maneuvers resulted in a pedestrian conflict compared with 19.5 percent of RTOG maneuvers that resulted in pedestrian conflicts. However, an additional 126 RTOR maneuvers (8.5 percent) resulted in cross-traffic conflicts. Thus a total of 22.7 percent (14.2 + 8.5) of illegal RTOR maneuvers resulted in a conflict, compared with 19.5 percent of RTOG conflicts. Thus, although illegal RTOR maneuvers result in a slightly higher rate of total conflicts than RTOG (22.7 to 19.5 percent), fewer pedestrian conflicts occurred with illegal RTOR maneuvers than with RTOG (14.2 percent compared with 19.5 percent). It should be mentioned that pedestrians may legally cross the street in the near crosswalk with RTOR and the far crosswalk with RTOG.

Status of Violations to the Stopping Requirement at RTOR-Permitted Sites

Data were collected at 29 RTOR-allowed approaches in the three cities relative to the frequency of vehicles making a full stop, rolling stop, or no stop when turning right on red, as summarized in Table 6. In addition, stopping data were also collected at 28 stop sign locations for comparison purposes. A total of 4 hr of data were collected per approach, for a total of approximately 228 hr of data. Conflict data were not collected relative to stopping characteristics data.

For the 29 signalized approaches (with RTOR allowed), 26.2 percent of right-turn vehicles turned right on red overall, with a small variation between cities (from 24.2 percent in Dallas/Austin to 29.3 percent in Washington, D.C.). Of all the vehicles turning right on red at the 29 approaches, 14.8 percent were recorded as no-stops (turned as if a green light existed), 42.1 percent made rolling stops, and 43.1 percent made full stops. Thus 56.9 percent (42.1 + 14.8 percent) of motorists violated the RTOR law by not making a full stop before turning right on a red signal. Of the 43.1 percent full stops, 36.0 percent were forced to stop (i.e., by oncoming traffic or pedestrians) and 7.1 percent were voluntary stops.

An analysis by city revealed that total violations (no-stops plus rolling stops) were the highest in Washington, D.C. (with 61.4 percent of vehicles not fully stopping) and Detroit (59.1 percent of vehicles not fully stopping), and lowest in Dallas/Austin (50.3 percent of vehicles not fully stopping).

The percentage of right-turning vehicles stopping at RTOR-allowed sites was compared with those at stop sign locations, because motorists under both situations are required to make a full stop and then turn right after yielding to pedestrians and cross-street traffic. Thus the relative magnitude of nonstopping motorists at RTOR-allowed locations could be discussed in terms of another type of traffic control. Such comparisons of compliance between RTOR-allowed sites and stop sign locations have been made in several previous RTOR studies.

The overall violation rate (i.e., motorists not fully stopping) of right-turn vehicles was found to be 68.2 percent at stop sign locations compared with 56.9 percent at the RTOR-permitted sites, a difference of 11.3 percent. Rolling stops were higher at the stop sign locations (57.3 percent) compared with RTOR-allowed locations (42.0 percent). However, the percentage of no-stops was 14.8 percent at the RTOR-permitted locations, compared with 10.9 percent at the stop sign locations.

The overall percentage of voluntary stops was approximately 7 percent at both the RTOR-allowed

TABLE 6 Summary of Data Collected at RTOR-Permitted and Stop Sign Approaches

Approach	Right Turns per Hour	RTOR per Hour	RTOR (%)	Stopping Violations per Hour	Stopping Violations (%): Total Violations	Rolling Stop	No Stop	Full Stops (%): Total	Voluntary	Forced	No. of Approaches
RTOR-allowed approaches (total)	67.3	16.3	26.2	9.2	56.9	42.0	14.8	43.1	7.2	36.0	29
Detroit	64.1	15.1	25.0	9.3	59.1	46.5	12.6	40.9	8.5	32.4	9
Washington, D.C.	69.3	19.5	29.3	11.7	61.4	41.7	19.7	38.6	4.6	34.1	10
Dallas/Austin	68.0	14.1	24.2	6.7	50.3	38.4	11.9	49.7	8.7	41.0	10
Stop sign approaches (total)	38.3		NA	27.1	68.2	57.3	10.9	31.8	7.1	24.7	28
Detroit	59.3		NA	43.5	67.3	56.5	10.8	32.7	6.0	26.7	10
Washington, D.C.	35.5		NA	22.5	63.0	49.5	13.5	37.0	10.1	26.9	8
Dallas/Austin	19.5		NA	14.3	73.3	64.3	8.9	26.7	5.9	20.8	10

Note: NA = not applicable.

sites and the stop sign locations. However, 36 percent of the RTOR motorists were forced to stop at the RTOR-allowed locations compared with 24.7 percent at the stop sign locations, a difference of 11.3 percent. Note that a difference of 11.3 percent was also found between RTOR-allowed and stop sign approaches in terms of overall violations. This indicates that the slightly higher percentage of vehicles stopping at the RTOR locations (43.1 percent) compared with the stop sign locations (31.8 percent) could be largely the result of more opportunities for a rolling or no stop at the stop sign locations. Thus it appears that there is little difference in driving behavior in terms of stopping compliance between the RTOR-permitted locations and the stop sign locations.

The overall 56.9 percentage of vehicles not fully stopping (before turning right on red) is higher than the 40 percent found by Davis and Mullowney (6) in a 1983 study of intersections in New Jersey. Part of the differences could be slight variations in the definitions of a rolling or full stop, differences in site characteristics, or differences in motorist behavior at the New Jersey sites. However, a 1978 study of 11 sites in Providence, Rhode Island, and 12 locations in Springfield, Massachusetts, found that 65 and 28 percent of the motorists, respectively, did not stop before turning right on red. The high compliance rate in Springfield was attributed to the newness of the RTOR maneuver and the sign reminding them to stop (8). In a 1981 study, Baumgaertner (3) found that 64.4 percent of drivers failed to stop in Maryland before turning right on red. Thus other recent studies have found rates of nonstopping to range from about 28 percent to 65 percent, and the finding of 56.9 percent in this study falls within this range. It appears, however, that the percentage of nonstopping vehicles varies from city to city and may have changed in recent years.

It should also be mentioned that conflict data were not collected relative to stopping characteristics of RTOR vehicles. The conflicts resulting from RTOR are highly dependent on pedestrian volumes, RTOR volume, side-street volume, and numerous locational factors. Thus a direct comparison of conflicts is not appropriate between RTOR-allowed and RTOR-prohibited sites, because sites may differ greatly in terms of pedestrian volume, RTOR volume, and so forth. It is possible, however, that a conflict problem on an intersection approach may exist because of the failure of RTOR vehicles to make a full stop. The magnitude of this RTOR conflict problem can only be determined on the basis of stopping characteristics data and corresponding conflict data at a large number of sites with RTOR allowed (i.e., 100 or more) with a variety of site and volume conditions.

Locational Factors Related to RTOR Violations

The next phase of the study involved determining geometric, traffic control, and other locational characteristics that are associated with high RTOR violation rates. The basic analysis approach for determining such related factors involved a safety engineering study of individual sites. This first involved ranking approaches by violation rate and then identifying common locational factors associated with high and low violation sites. This ranking was generated first for the 110 sites with RTOR prohibition, and then a separate ranking was developed of the 29 RTOR-allowed sites. These two situations are discussed in the following sections.

Locational Factors for RTOR-Prohibited Sites

Violation rates (turning right on red) at RTOR-Prohibited sites ranged from 0 to 25.6 percent. A distribution of the violation rates of the 110 sites was as follows:

Violations (%)	No. of Sites
0-1	13
1-2	21
2-3	19
3-4	11
4-5	6
5-6	11
6-8	7
8-10	4
10-12	7
12-18	8
18-30	3

The top 29 sites (26.3 percent) were found to have a violation rate greater than 6.0 and were labeled as the high-violation group. A total of 34 sites (30.9 percent) had a violation rate of 2 percent or less and were labeled as the low-violation group.

For the locations in the high- and low-violation groups, factors were identified that were related to high and low violations based on field inspections, a review of site diagrams, and a review of computer summaries of traffic data, signal data, and other information at each site. Location factors were identified as related to high violations if they were routinely found in the high-violation group but not in the low-violation group.

Traffic and roadway factors found to be typically associated with high violation rates include the following variables (individually or in various combinations):

1. Confusing or inappropriate partial prohibition signs [i.e., NTOR-SCHOOL DAYS ONLY sign located near a university, because motorists are not sure whether classes are in session on Saturdays, during summer sessions, and so forth; another NTOR sign near an elementary school prohibited RTOR during times after children had already arrived at school (9:00 a.m. to 2:00 p.m.) and ended before children left for home in the afternoon];
2. NTOR signs that are located on the far side or are inconspicuous to the motorists, particularly when placed on the far side across wide streets;
3. Combinations of low cross-street volume and low pedestrian volumes;
4. Approaches with easy right-turn maneuvers or right turns less than 90 degrees such as at Y-intersections, particularly with low conflicting movements;
5. Long cycle lengths that result in excessive waiting time for right-turn motorists;
6. High-speed ramps that form a T-intersection with a low-volume cross street;
7. Wide one-way streets on the cross street with low volume in the curb lane;
8. Confusing, multileg intersection approaches or approaches with an offset cross street;
9. Approaches where RTOR prohibition does not appear to be justified for some or all periods of the day because of low traffic volumes and little or no pedestrian traffic; and
10. Low right-turn volume per hour. [However, this is somewhat misleading because the percentage of violations is the total RTOR vehicles divided by the right-turn vehicles (including RTOG). As right-turn volume increases, a higher percentage of right-turn vehicles are trapped second, third, or fourth in line and cannot physically make an RTOR.]

The intersection approaches with low RTOR violation rates were also studied to determine related factors. The factors typically found at low-violation sites included the following variables:

1. Double NTOR signs located on the near and far sides, or NTOR signs that were located overhead or in a conspicuous location for stopped motorists;
2. High pedestrian volumes in either the near or far crosswalk (reduced opportunity for an RTOR);
3. High cross-street volume (reduced number of gaps and lower opportunity for an RTOR);
4. Crosswalk set back from the intersection farther than normal, combined with high pedestrian volumes;
5. Short signal cycle length;
6. A sharp right-turn maneuver (greater than 90 degrees) combined with poor sight distance;
7. High right turns per hour (however, this is misleading, as discussed previously); and
8. A cross street with on-street parking on the right, which forces an RTOR vehicle to make a wide turn beyond parked cars.

These results appear to indicate that motorist violations to NTOR signs are high when the signs are obscure or when it is not obvious to the driver why RTOR is prohibited (i.e., low pedestrian and cross-street volume and good sight distance). Drivers are particularly likely to run an NTOR sign at sites with long cycle lengths (when waiting time may be long). Some of the factors in the previous list were found to be useful for developing countermeasures.

Consideration was given to conducting more formal statistical analysis techniques to further support the factors that are associated with high and low violation rates. A branching analysis was conducted to identify roadway variables (independent variables) that account for the largest amount of explained variance in the violation rate (dependent variable). In addition to the branching analysis, preliminary Pearson correlation analysis and analysis of variance (ANOVA) tests were conducted. However, correlation coefficients were low (less than 0.3) for individual variables, and the ANOVA test required a larger data base of approaches to control for the interaction of traffic and roadway variables as they affect RTOR violation rates. It was evident that an engineering analysis of each approach was most useful in determining individual factors or combinations of factors that were related to high or low violation rates.

Locational Factors for RTOR-Permitted Sites

A detailed study was also made of traffic, geometric, and other factors at each of the 29 RTOR-permitted approaches to identify factors related to stopping violations (i.e., not making a full stop before turning right on red). At the 29 signalized approaches with RTOR permitted, no-stops ranged from zero to 45.2 percent, and total stopping violations (no stops plus rolling stops) ranged from 21.2 to 88.9 percent. One approach that had a sign posted RIGHT TURN ON RED ALLOWED AFTER STOP experienced 26.7 percent no-stops and 68.6 percent total stopping violations, compared with an overall average of the 29 sites of 14.8 percent no-stops and 56.9 percent total violations. It is possible that the sign had an effect of increasing stopping violations at the site, although insufficient data existed to verify this.

Locational factors found to be associated with a high rate of stopping violations included

1. Good sight distance with low pedestrian volume and low cross-street volume;
2. High right-turn volume;
3. Low pedestrian volume;
4. Low cross-street volume;
5. Unusual signal timing, such as split phasing, which minimized or eliminated conflicting traffic for part of the red interval;
6. Offset cross street (which lowered or delayed conflicting traffic and increased the opportunity for an RTOR rolling stop or no-stop); and
7. Nearby signalized intersection on the cross-street upstream, which created artificial gaps in cross-street traffic and provided greater opportunities for RTOR rolling stops or no-stops.

The factors found to be associated with low stopping violations at RTOR-allowed approaches included

1. High cross-street volume;
2. Poor sight distance (i.e., on-street parking on the cross street to the left of the approaching right-turn motorists);
3. High speed of cross street; and
4. High pedestrian volume.

These results indicate that drivers were more likely to comply with the stopping requirement when forced to do so (i.e., high pedestrian volume or cross-street traffic). Also, poor sight distance was a factor associated with high compliance, because drivers often made a full stop to look for cross-street traffic. During intervals of little or no pedestrian or conflicting traffic (such as with special signal phasing), motorists were less likely to make a full stop before turning right on red.

More formal statistical analysis techniques were not used for identifying related factors, because such analyses are not particularly appropriate for relatively small sample sizes of this type. The factors in the previous list were considered for development of possible countermeasures relative to RTOR stopping violations, as discussed in the next section.

SELECTION OF CANDIDATE COUNTERMEASURES

The factors related to high and low RTOR violations were studied and then grouped into corresponding high- and low-violation categories (Table 7). For example, one of the factors related to high violation of NTOR signs was long cycle length (excessive delay to right-turn motorist). A corresponding factor related to low violation rates was short cycle length. Thus, by grouping these factors, candidate countermeasures were developed, such as improving signal timing or installing traffic actuation devices.

As noted in Table 7, seven basic situations were found for which countermeasures could be proposed. Four of these situations related to violations of RTOR prohibitions and three involved the incidence of stopping violations (vehicles not making a full stop before an RTOR maneuver) where RTOR is allowed. For several of the violation causes, countermeasures were suggested that either may have an effect on the violation rates or may reduce the degree of hazard resulting from the violations. For example, for RTOR violations that involve not making full stops before turning right on red, countermeasures that may reduce the danger of such violations may include

1. Relocating the crosswalk farther from the intersection,
2. Warning pedestrians of possible right-turn danger through the use of WALK WITH CARE pedestrian

TABLE 7 Summary of Development of Candidate Countermeasures Based on Factors Related to RTOR Violations

High/Low Situation	Type of Violation Problem	Factors Related to High RTOR Violations	Factors Related to Low RTOR Violations	Candidate Countermeasures
1	RTOR where prohibited	NTOR signs located on far side or inconspicuous to the motorist	Double NTOR signs located on near and far side, or NTOR signs that are located overhead or in a conspicuous location for stopped motorists	1. Illuminate NTOR sign 2. Increase sign size to improve visibility 3. Relocate signs to near signal placement 4. Use double NTOR signs for redundancy 5. Use NTOR signs with red ball 6. Advanced warning of NTOR 7. Remove roadside clutter (to make NTOR sign more conspicuous) 8. Provide or improve intersection lighting
2	RTOR where prohibited	Confusing or inappropriate partial prohibition signing	Clear and visible NTOR signing	1. Prohibit RTOR only during the hours of heavy pedestrian travel 2. Use full RTOR prohibition on the approach 3. Use variable message NTOR signs 4. NTOR illuminated signal to be activated only during periods when RTOR is prohibited
3	RTOR where prohibited	Long cycle lengths (excess waiting time for right-turn motorists)	Short signal cycle lengths	1. Improve pedestrian signal display 2. Retime the traffic signal to provide better operations 3. Install presence detectors at traffic-actuated approaches to provide more efficient signal operation 4. Remove unwarranted traffic signals
4	RTOR where prohibited	Easy right-turn maneuver	Crosswalk set back from intersection farther than normal combined with high pedestrian volumes	1. Relocate crosswalk 2. Offset or angled stop bar 3. Special pavement marking in crosswalk
5	Stopping violations where RTOR allowed	Unusual signal timing	Lack of opportunity because of consistent traffic flow on cross street	1. Install flashing red right turning arrow to encourage full stop 2. Install NTOR sign if warranted 3. Retime traffic signal 4. Install part-time RTOR prohibition sign or variable message NTOR display 5. Install RIGHT TURN ON RED AFTER STOP sign to encourage full stops 6. Use special pedestrian signal display (i.e., WALK WITH CARE signal message during the WALK interval) 7. Install special pavement markings in crosswalk (i.e., LOOK FOR TURNING VEHICLES)
6	Stopping violations where RTOR allowed	Good sight distance	Poor sight distance	1. Install RIGHT TURN ON RED AFTER STOP sign to encourage full stops 2. Install YIELD TO PEDESTRIAN sign 3. Relocate crosswalk farther from intersection
7	Stopping violations where RTOR allowed	High right-turn volume, low pedestrian volume, or low cross-street volume	Low right-turn volume, high pedestrian volume, or high cross-street volume (or speed)	1. Install RIGHT TURN ON RED AFTER STOP sign to encourage full stops 2. Install NTOR sign if warranted 3. Install part-time RTOR-prohibition sign or variable-message NTOR display 4. Install YIELD TO PEDESTRIAN sign 5. Install PEDESTRIANS WATCH FOR TURNING VEHICLES sign 6. Use special pedestrian signal display (i.e., WALK WITH CARE signal message during the WALK interval) 7. Retime traffic signal 8. Remove unwarranted traffic signals 9. Relocate crosswalk further from intersection 10. Use special pavement marking in crosswalk (i.e., LOOK FOR TURNING VEHICLES) 11. Construct pedestrian overpass or underpass 12. Construct separate right-turn lane

Note: The countermeasures in this table were intended to correspond to traffic engineering treatments (i.e., improvement of traffic control devices or transportation facilities). It is recognized that provision of selective police enforcement and use of public education programs may also be of considerable benefit with respect to improving compliance and understanding or both of RTOR requirements and devices.

signals or LOOK FOR TURNING VEHICLES pavement markings, and

3. Constructing a pedestrian overpass or underpass to physically separate pedestrians and motorists.

Although RTOR motorists should yield to pedestrians, pedestrians should also be alert whenever crossing the street, because the pedestrian is usually the one who is injured in the event of a vehicle-pedestrian accident. Thus some of the countermeasures listed in Table 7 are intended to reduce violations related to RTOR, and other countermeasures are intended to reduce the potential hazard of RTOR maneuvers (either legal or illegal).

Based on all of the sources discussed previously, 30 potential RTOR-related accident countermeasures were devised (Table 8). These were categorized as they relate to signs, signals, pavement markings, design treatments, or other types of countermeasures.

For each countermeasure, a description is given along with comments and an indication regarding whether the countermeasure was selected for field testing. Many of these countermeasures may relate not only to RTOR and RTOR-pedestrian accidents, but to pedestrian accidents in general. A few of the countermeasures (i.e., eliminating unwarranted signals and retiming signals) may also affect other types of accidents (rear end, right angle, and so forth) and intersection operations (delay, congestion).

SUMMARY OF FINDINGS AND CONCLUSIONS

The purpose of this analysis was to conduct observational studies at signalized intersections to deter-

TABLE 8 Countermeasures Developed for RTOR

Category	Device	Description	Selected for Field Study	Comments
Signing	Full prohibition of RTOR	Install NTOR sign at locations with high traffic or pedestrian volumes, poor sight distances, at school crossings, or where other such factors influence the safe RTOR maneuver	No	There are some locations where RTOR maneuvers are unduly hazardous; although the MUTCD has guidelines on the application of NTOR signs, they are general and prone to a wide variety of interpretations; this leads to a nonuniform application of RTOR prohibitions; because conditions may change based on time of day, day of week, and season, a full-time prohibition may not always be warranted at a site
	Partial prohibition of RTOR for certain lanes or during specific times of the day	Install special signs that prohibit RTOR for certain times (7:00 a.m. to 7:00 p.m.), days (school days), conditions (when children are present), seasons (September to June), lanes (NTOR, except curb lane), or other factors	Yes	Because conditions may change at a site (by time of day or day of week), the prohibition should ideally only cover those times and conditions where warranted; however, some of the legends may require special knowledge by the motorists (school days), require motorists to drive "with one eye on the clock," or may be difficult to read
	YIELD TO PEDESTRIAN sign	Install a yield sign directed at turning motorists advising them to yield right-of-way to pedestrians	No	This device was tested in a previous FHWA study on pedestrian signalization alternatives and was found to be effective in reducing total right-turn conflicts with pedestrians
	Illuminate NTOR sign	Illuminate the NTOR sign for increased visibility; this could be accomplished by using an illuminated case sign (internal source) or external lighting	No	Designed for areas where there is a nighttime RTOR-related problem or where no intersection lighting exists or both
	Larger NTOR sign	Use an NTOR larger than the current MUTCD standard of 24 x 30 in. or 24 x 24 in.	Yes	NTOR sign should ideally be placed near the signal; it is applicable for near signal placement when the signal is located on the far side of a wide street or is otherwise difficult to read; it may be particularly helpful in cities or locations where overhead sign placement is not possible
	Near-signal placement of NTOR sign	Install NTOR sign on span arm, span wire, or signal pole near the signal head where motorist tends to look	No	MUTCD guidelines for NTOR sign placement state that signs should be located adjacent to the signal face to which they apply; many communities do not follow these guidelines and have the sign post mounted at the corner of the intersection
	Redundant NTOR signs	Install two or more NTOR signs on both posts (near or far side) and overhead to increase visibility of sign	No	Although this countermeasure is applicable for some locations with high violation rates, high conflict rates, or poor sign visibility, redundant sign placement should be minimized
	RIGHT TURN ON RED AFTER STOP sign	Install a sign that reminds motorist to come to a complete stop before turning on red	No	This device is intended to remind the driver to come to a full stop before making the RTOR maneuver, or to encourage more RTOR maneuvers where motorists are hesitant (and there are no conflicting pedestrian crossings or cross-street traffic)
	NTOR sign with red ball	Install a modified NTOR sign with a red ball in the center to draw attention to the sign	Yes	A sign with a red ball may catch the motorist's eye better; this device is currently used in some cities
	Advance warning of NTOR	Install a sign in advance of the intersection to warn motorists that there is an RTOR prohibition at the next intersection	No	This allows advance warning of conditions at the intersection and is consistent with positive guidance concepts; this sign may only add to the visual clutter of the roadside and may have minimal effect for those stopped at the signal

TABLE 8 Continued

Category	Device	Description	Selected for Field Study	Comments
Signing, continued	Electrical or mechanical variable message NTOR sign	Install signs that can display different messages for different signal intervals, times of day, or days of week	Yes	This device has two applications: (a) prohibit RTOR during portions of the day that have high pedestrian volumes or cross-street volumes, or (b) prohibit RTOR during portions of a cycle where a protected movement may conflict with the RTOR (such as an opposing protected left-turn maneuver); a blank-out display would avoid confusion when the message is not needed or other safety messages could be displayed; the cost for this device is expected to be high
	PEDESTRIANS WATCH FOR TURNING VEHICLES warning sign	Install a warning sign directed toward pedestrians to warn of turning vehicles; this device supplements pedestrian signals	No	This sign will not affect motorist behavior and is only applicable to pedestrians crossing the street; this may lead to additional visual clutter and is not effective for small children who cannot read; this device was tested in a previous FHWA study on pedestrian signalization alternatives and was found to be effective in reducing right-turn conflicts
Signals	Special pedestrian signal display (WALK WITH CARE)	Use a three-head signal that has a WITH CARE or other indication in yellow displayed during the WALK interval to warn of possible conflicts (i.e., WALK WITH CARE)	No	Special signal indications can be provided to remind the pedestrians to watch for turning vehicles; this type of device should only be used at locations where a known or potentially hazardous pedestrian problem exists, because overuse of such device could result in reduced effectiveness; this device was tested in a previous FHWA study on pedestrian signalization alternatives and was found to be effective in reducing right-turn pedestrian conflicts
	Retime traffic signal	Retime signal to reduce the conflicts and minimize delay; options include improved timing to accommodate flows, special pedestrian phasing, or use of multiphase operation	No	This is applicable to locations with high volumes of vehicle and pedestrian traffic, where turning movements are high, and where congestion is a problem; exclusive pedestrian crossing intervals, which have been noted to be related to lower pedestrain accidents, also increase delay and congestion to pedestrians and motorists
	Traffic-actuated signal	Use presence detectors to determine the right-turn demand and actuated signals to accommodate the demand and reduce the number of RTORs	No	May be applicable to some intersections with heavy right-turn demand
	Remove unwarranted traffic signals	Remove unwarranted signals and replace with other types of traffic control	No	Motorists lose respect for unwarranted signals, thereby increasing violations; many communities have begun programs to remove unwarranted signals where they no longer meet the warrants; although this may have the benefit of improving flow, reducing operating costs, and saving energy, pedestrians must cross the street without signal assistance
	Flashing red right-turn arrow	Install a flashing right-turn arrow to encourage motorists to come to a full stop before turning right on red	No	The flashing red arrow has been used in the past for right- and left-turn-on-red situations to stress the need for stopping before making an RTOR; this would require an extra signal lens; it may not convey a clear and simple meaning to all motorists and would require FHWA approval before use; it is currently not in the MUTCD
	NTOR signal installed in pedestrian signal hardware	Install an illuminated signal directed at motorists in pedestrian signal hardware to prohibit RTOR	No	This device uses existing pedestrian signal hardware (with a different lens) to display a blank-out or an NTOR indication to motorists; applicable for partial RTOR prohibitions; blank-out device minimizes confusion during RTOR-allowed periods
Pavement markings	Relocate crosswalk farther from intersection	Move the crosswalk farther from the intersection to increase visibility of pedestrians	No	Moving the stop bar and crosswalk farther from the intersection may discourage RTOR and increase the visibility of pedestrians; however, motorists failing to stop at the stop bar will block the crosswalk; this device may result in less sight distance of cross-street traffic and may encourage jaywalking
	Offset or angled stop bars	Angle or offset the stop bar so that drivers in the middle lanes are stopped farther back from the intersection than right-turn vehicles in the curb lane	Yes	For sites where RTOR is allowed; applicable to multilane approaches where there is a high incidence of truck and bus traffic that obstructs the drivers' view; allows the RTOR vehicle to see cross-street traffic and pedestrians for a safer turn; the effectiveness may be reduced if vehicles in the middle lanes do not observe the offset stop bar

TABLE 8 Continued

Category	Device	Description	Selected for Field Study	Comments
Pavement markings continued	Pavement marking	Pavement marking message in crosswalk to remind pedestrians to watch for RTOR vehicles (i.e., LOOK FOR TURNING VEHICLES)	Yes	The message is not visible to the motorist and will have no effect on driver reactions; installing pavement markings could create a slick surface for pedestrians unless a textured surface is used
Design	Pedestrian barriers	Install barriers to channelize pedestrians to the crosswalk, thereby minimizing the conflict area	No	The pedestrian barrier is also expected to reduce other types of pedestrian accidents, particularly dart-out and jaywalking-related accidents; however, barriers may cause difficulty in accessing parked vehicles along the curb, may be unsightly, and may create another roadside obstacle
	Pedestrian overpass or underpass	Grade separation of pedestrians and motorists to eliminate conflicts	No	Applicable to wide, high-speed intersections with safety problems; very expensive countermeasure, and the cost cannot be justified based on RTOR accidents alone; there may also be difficulties in accommodating elderly and handicapped pedestrians and bicyclists
	Far side bus stops	Allow buses to stop to drop-off and pick-up passengers only after crossing the intersection	No	Applicable where RTOR is allowed; eliminates congestion at the approach but may create a sight obstruction; far side bus stops are being used by many transit agencies to reduce intersection delays
	Eliminate parking near the intersection	Remove on-street parking near the intersection on either side or both sides of the street	No	On-street parking poses a site obstruction when near the crosswalk; this countermeasure may reduce other types of accidents at the intersection and may also increase capacity; however, it reduces parking availability; parking restrictions must be enforced to be effective
	Separate right-turn lane	Provide a separate lane for right turns and thus increase the opportunities for vehicle to make an RTOR	No	Applicable to sites with high volumes of right-turn traffic; increases the use of RTOR where RTOR is allowed; reduces intersection delay and increases capacity
Other	Intersection lighting	Illuminate the intersection to provide better visibility of pedestrians at night	No	Applicable to locations with high nighttime pedestrian volumes and where nighttime safety problems exist; may reduce other types of nighttime accidents at the intersection and may be useful in reducing crime at night
	Education campaign	Educate the public by using various forms of media to increase awareness and to teach proper understanding of RTOR	No	Educational campaigns can be directed at both the motorists and pedestrians related to RTOR safety and other safety issues; educational programs may not reach all individuals and may not have lasting impact; difficult to evaluate, especially relative to RTOR
	Clear roadside clutter	Remove roadside items to increase motorist visibility of pedestrians and traffic control devices	No	Removing all but essential roadside items should improve the motorist's ability to perceive pedestrians and traffic control devices and reduce distractions; may reduce other types of intersection accidents and improve aesthetics
	Selective traffic enforcement	Enforce violations of the NTOR sign and the requirement to complete a full stop before turning right on red where permitted; other pedestrian and motorist laws can also be enforced simultaneously	No	Enforcement or police presence near the intersection may reduce other violations; effectiveness may diminish once the police leave, because manpower is limited in most agencies; police time may be better spent in other areas of traffic enforcement or crime protection

mine current motorist compliance to RTOR prohibition and the requirement to make a full stop before turning right on red (where permitted). Traffic, geometric, and other physical site characteristics were collected in Detroit, Washington, D.C., and the Dallas/Austin area, and an in-depth engineering study was conducted at each of 110 intersection approaches where RTOR is prohibited. Data were also collected at 29 RTOR-allowed intersection approaches and 28 stop sign approaches relative to stopping characteristics (i.e., percentage of full stops, rolling stops, and no-stops of RTOR vehicles). Then locational factors were identified relative to high and low violation rates. The following is a summary of key findings and conclusions:

1. Overall, only 3.7 percent of all right-turning drivers violate the RTOR prohibition signs, based on a sample of more than 67,000 drivers. However, of those motorists given an opportunity to commit an RTOR violation, about 20 percent of them violate the NTOR sign.
2. Of the drivers who commit an RTOR violation, about 23.4 percent of them result in conflicts with pedestrians or cross-street traffic. However, less than 1 in 100 of the total right-turn vehicles is involved in an RTOR-related conflict.
3. At a sample of RTOR-prohibited sites, 22.7 percent of the illegal RTOR maneuvers resulted in a conflict with cross traffic or pedestrians. However, only 14.2 percent of RTOR maneuvers resulted in a

conflict to pedestrians, compared with 19.5 percent RTOG maneuvers that involve a pedestrian conflict.

4. Of the 29 intersection approaches with RTOR allowed, 26.2 percent of right-turn vehicles turned right on red. Of the vehicles turning right on red, the violation rate (not making a full stop) was 56.9 percent. This rate was higher for Washington, D.C. (61.4 percent of vehicles not fully stopping) and Detroit (59.1 percent), compared with Dallas/Austin (50.3 percent).

5. The overall violation rate (percent not fully stopping) at the 28 stop sign approaches was 68.2 percent compared with 56.9 percent for signalized approaches with RTOR allowed, a difference of 11.3 percent. However, 36 percent of vehicles were found to stop at RTOR-allowed approaches compared with 24.7 percent at stop sign locations. Thus the 11 percent higher violation rate at stop sign locations may be at least partly explained by the greater percentage of opportunities for a rolling stop or no-stop.

6. Examples of physical site factors found from in-depth site studies to be related to high RTOR violation rates include confusing or inappropriate partial prohibition signs; far side or inconspicuous NTOR signs; long cycle lengths; confusing multileg intersection approaches; unjustified RTOR prohibition; split-phasing of the signal, which creates low opposing traffic for RTOR maneuvers; and combinations of a low volume or high speed of cross-street traffic and low pedestrian volumes.

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