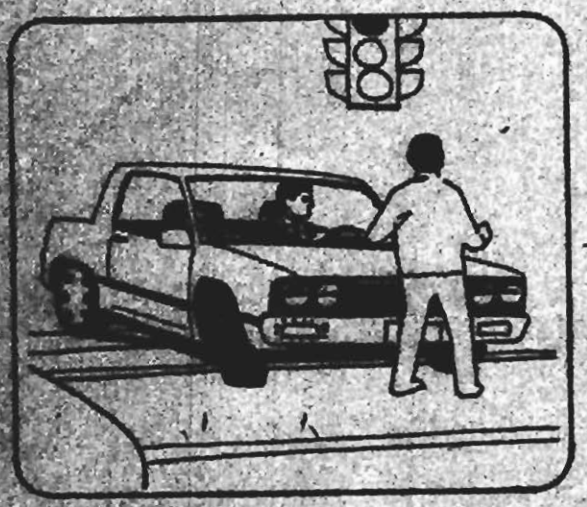
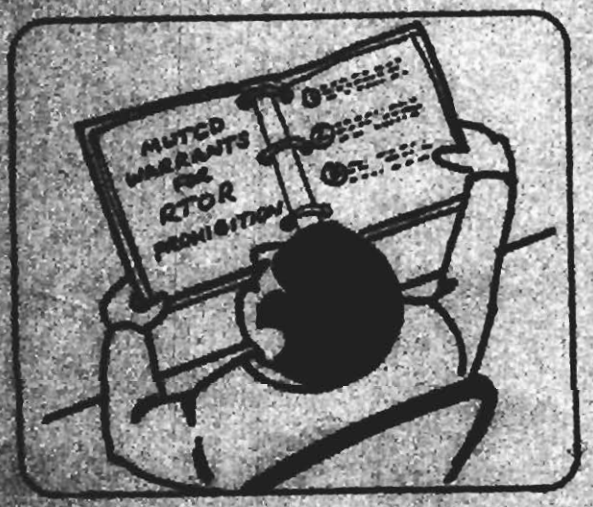
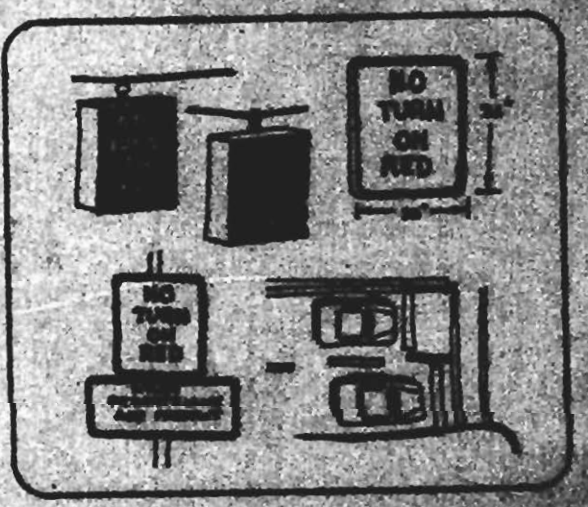
METHODS OF INCREASING SAFETY AT RIGHT-TURN-ON-RED INTERSECTIONS

USER'S MANUAL

March 1985







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16 Abstract

The purpose of this study was to determine current motorist compliance to RTOR regulations, develop and field test countermeasures for RTOR pedestrian accidents, and develop improved warrants and guidelines for prohibition of RTOR. Based on data from several U.S cities, only 3.7 percent of all right turning drivers violate NO TURN ON RED (NTOR) signs. However, of drivers with an opportunity to turn right on red, 20 percent violated the sign. At locations with RTOR allowed, 56.9 percent of motorists do not come to a complete stop before turning right on red.

Based on conflict and violation data, 30 countermeasures were developed as possible treatments for RTOR-pedestrian accidents. Seven of these were field tested, including an offset stop bar, a red ball (symbolic) NTOR sign, a larger 30x36-in (75x90-cm) NTOR sign, a LOOK FOR TURNING VEHICLES pavement marking, a NTOR WHEN PEDESTRIANS ARE PRESENT sign, and an electronic variable message (blank-out) NTOR sign. Several promising applications for the devices were recommended. A critique was made of the current MUTCD guidelines on RTOR prohibition. Based on an analysis of conflicts at 199 intersection approaches, improved guidelines were recommended.

The final report consists of two volumes. Volume I is the Executive Summary and Volume II is the Research Report. This User's Manual was prepared to provide guidance to highway agency officials on techniques to improve pedestrian and motorist safety with respect to RTOR.

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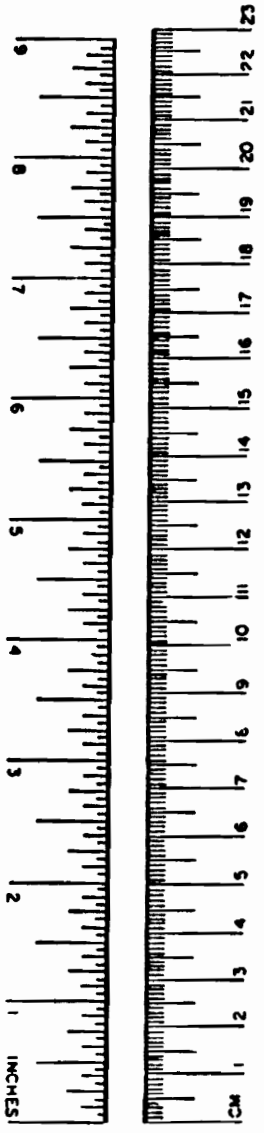
METRIC CONVERSION FACTORS

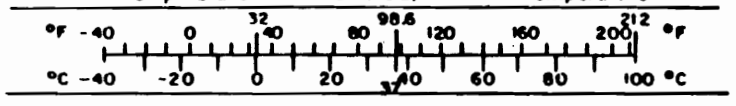
APPROXIMATE CONVERSIONS FROM METRIC MEASURES

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
LENGTH				
in	inches	2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
AREA				
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.6	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
MASS (weight)				
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons(2000lb)	0.9	tonnes	t
VOLUME				
tsp	teaspoons	5	milliliters	ml
tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
TEMPERATURE (exact)				
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C



APPROXIMATE CONVERSIONS FROM METRIC MEASURES

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
LENGTH				
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
AREA				
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares(10,000m^2)	2.5	acres	
MASS (weight)				
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000kg)	1.1	short tons	
VOLUME				
ml	milliliters	8.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	36	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
TEMPERATURE (exact)				
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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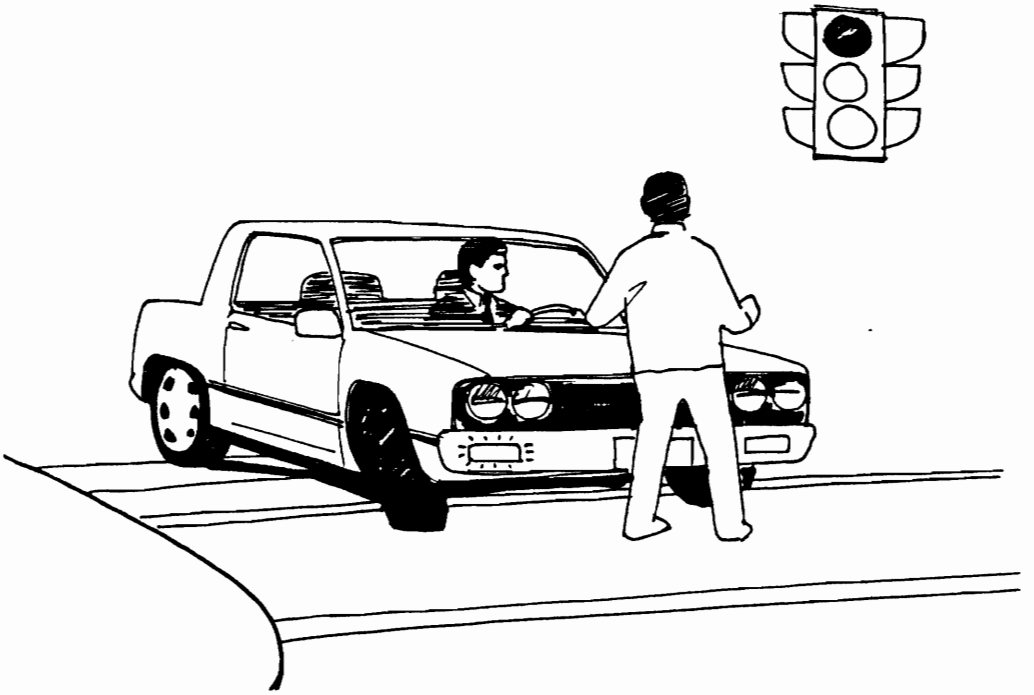
CHAPTER I - INTRODUCTION



The option of motorists to make a right-turn-on-red (RTOR) at signalized intersections after stopping and yielding the right-of-way to pedestrians and other traffic is now a widely accepted traffic regulation in the United States. RTOR maneuvers are now generally permitted nationwide at all signalized intersection approaches, unless the turn is specifically prohibited by a sign. The only exception to the general permissive rule (or Western rule) is New York City, where RTOR maneuvers are prohibited unless specifically permitted by a sign. In addition to RTOR, many states now permit left-turn-on-red (LTOR) from a one-way street onto a one-way street, unless the maneuver is specifically prohibited by a sign.

In spite of the widespread adoption of RTOR, the issue remains controversial. Proponents of RTOR cite over 40 years of successful experience with the maneuver in California and other western States and suggest that RTOR results in savings of time and motor fuel by reducing vehicle delay. They also feel that RTOR reduces congestion and is not hazardous, since RTOR-related crashes represent a small percentage of accidents at signalized intersections. Opponents of the measure suggest that RTOR is hazardous

to pedestrians and bicyclists, and especially to children, elderly, and handicapped persons. They also feel that motorists disregard the law by failing to stop and yield to traffic and that the time savings are not significant compared to the hazards associated with RTOR.

While controversy on RTOR may never be fully resolved, there are several issues that remain clear. First of all, the permissive RTOR rule (or Western rule) is now an issue that State and local highway agencies must face, and respond to at least for the present time. Secondly, this requires those agencies to consider MUTCD warrants and guidelines for RTOR prohibition and determine which intersection approaches should be signed for RTOR prohibitions (i.e., NO TURN ON RED). Thirdly, there are other types of RTOR-related countermeasures that may be considered at both RTOR-allowed and RTOR-prohibited sites.

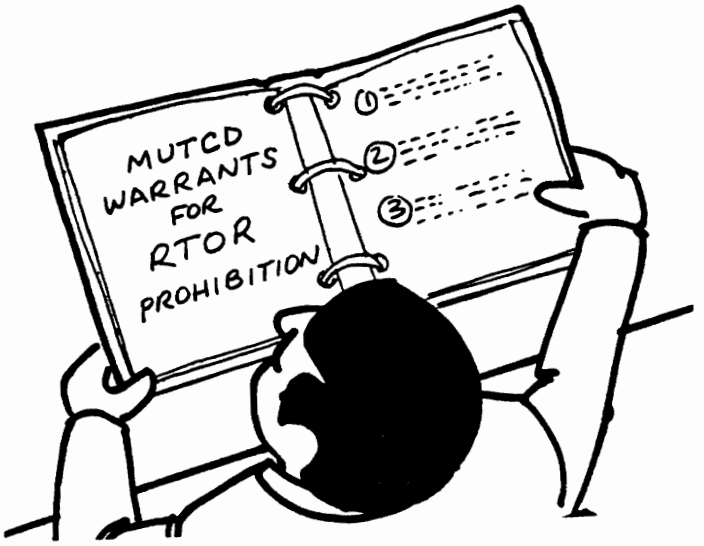
Considerable research has been completed in recent years which has discussed information to assist the traffic engineer in determining where RTOR should be prohibited. For example, one recent study for FHWA by Zegeer and Cynecki [1], involved the development of 30 potential countermeasures related to RTOR, and a field evaluation was conducted for 7 of these countermeasures. The results of this study, and many others, need to be compiled for use by traffic engineers in analyzing and correcting RTOR-related problems.

The objectives of this User's Manual, therefore, are to provide detailed guidance to state and local traffic engineers regarding:

1. More appropriate and uniform application of the MUTCD warrants and guidelines for RTOR prohibition.
2. The systematic identification of RTOR-related problems and the selection, implementation, and evaluation of various RTOR-related countermeasures (i.e., signs, pavement markings, design improvements, etc.).

The first issue on warrants and guidelines for RTOR prohibition is covered in Chapter II. Chapter III provides a step-by-step procedure for countermeasure selection and use, which should be considered at sites with and without RTOR-prohibition. Chapter IV provides a list of references related to RTOR along with a summary of the specific topics covered in each. Sample site data forms are given in the Appendix.

CHAPTER II - GUIDELINES FOR RTOR PROHIBITION



At the present time, RTOR is allowed at signalized intersections in all States, unless otherwise signed, except for New York City. Concern over the permissive RTOR rule initially caused many local agencies to install signs prohibiting RTOR at many intersections. Section 2B-37 of the MUTCD currently stipulates that a NO TURN ON RED sign (R10-11a) "may be considered" when one or more of the following conditions are found based on an engineering study:[2]

1. Sight distance to vehicles approaching from the left (or right, if applicable) is inadequate.
2. The intersection area has geometrics or operational characteristics which may result in unexpected conflicts.
3. There is an exclusive pedestrian phase.
4. Significant pedestrian conflicts are resulting from RTOR maneuvers.
5. More than three RTOR accidents per year have been identified for the particular approach.
6. There is significant crossing activity by children, elderly, or handicapped people.

Some people contend that these current warrants for RTOR prohibition are highly subjective and have resulted in considerable uncertainty and differing interpretations by local and State agencies. As a result, the application of the RTOR prohibition has not been uniform nationwide.

Many city traffic engineers have attempted to conscientiously utilize the MUTCD warrants and have been confused or frustrated. Some cities which initially prohibited RTOR at a high percentage of intersections (after the implementation of the permissive RTOR laws) have been slowly removing a portion of those prohibition signs. Other cities, particularly in the western U.S., have reacted by installing few or no RTOR prohibition signs.

Ideally, warrants for RTOR prohibition should contain adequate objectivity to provide helpful guidance to traffic engineers on where to prohibit RTOR. However, the guidelines must also contain enough flexibility to allow for some discretion by the local engineer based on the traffic and pedestrian volumes, roadway conditions, pedestrian and motorist behaviors, and other unique site and regional conditions.

In response to the need for improved warrants for RTOR prohibition, various state and local agency guidelines and several from recent research studies have been published as alternatives. One of the more recent research studies in this regard [1] involved the collection and analysis of roadway data, traffic data, and pedestrian-vehicle conflict data at 199 intersection approaches for use in recommending guidelines for RTOR prohibition. The study was able to determine levels of pedestrian volume, accidents, conflicts, and other site characteristics which were determined to be associated with safety or operational problems.

The MUTCD warrants should be followed by all highway officials in determining where RTOR should be allowed or prohibited. However, the application of the current MUTCD warrants requires considerable judgement by the traffic engineer to answer such questions as:

- What level of sight distance is considered to be "inadequate"? How should sight distance be measured? (Warrant 1).
- What specific types of geometrics or operational characteristics may result in "unexpected conflicts?" (Warrant 2).
- What are "significant" levels of pedestrian conflicts? How are such conflicts defined and measured? How long a time is needed for measuring conflicts and for what periods of the day? (Warrant 4).
- In using the accident warrant, what types of accidents are considered to be RTOR-related? How can this be determined from police accident reports? (Warrant 5).
- What is considered to be "significant crossing activity" by children, elderly, or handicapped people? (Warrant 6).

The intent of this chapter of the User's Manual is to provide some helpful guidance on these and other questions related to the six MUTCD warrants on RTOR prohibition. It would be inappropriate to give highly rigid criteria that must be precisely followed. Instead, some information is summarized which provides:

- Definitions of some terms.
- Suggested data collection methods.
- Levels of RTOR conflicts which have been measured at numerous locations in the U.S.
- Specific geometric conditions which have been found to be associated with high violation rates and/or high conflict rates.

While this information should be of some benefit, the application of the MUTCD warrants must still rely on the judgement of the local traffic engineer.

It should be remembered that RTOR prohibition is not a cure-all for all RTOR problems. In fact, the ITE 4A-17 Technical Committee [3] has made recommendations relative to RTOR prohibitions, as given in figure 1. Among other things, the Committee recommended that "less restrictive alternatives should be considered in lieu of prohibiting turns on red." Chapter III of this User's Manual provides a detailed procedure for considering various countermeasures related to RTOR safety and operational problems.

1. Engineering judgment is the basis for each potential turn on red prohibition. Prohibition should be considered only after the need has been fully established and less restrictive methods have been considered.
2. Part-time prohibitions should be discouraged; however, they are preferable to full-time prohibitions when the need occurs for only short periods of time. It is not good engineering practice to prohibit right turns on red on the grounds that it is of little benefit during some hours of the day. The use of disappearing legend signs for part-time prohibitions and where desired in the vicinity of railroad crossings is recommended.
3. Less restrictive alternatives should be considered in lieu of prohibiting turns on red. Some examples of less restrictive measures are signs such as "No Turns on Red to Henry Street" or "Right Turn on Red Right Lane Only." Such devices can provide the intended prohibitions without inconveniencing all right-turning traffic.
4. Although many authorities do not perceive the need to prohibit turns on red at multiphased signals, others find there is a need. Where such prohibitions are considered necessary, consideration should be given to the providing of right turn indications for the main street during the cross street left-turn phases.
5. The definition of specific right turn on red accident criteria may be inappropriate. The accident history of the intersection should be analyzed with prohibition of turns on red as one possible remedy. Experience may indicate that severe sight distance restrictions or deceptive geometrics can be related to turn on red accidents.
6. Universal prohibition at "school crossings" should not be made but rather restrictions should be sensitive to special problems of pedestrian and/or bicycle conflict, such as the unpredictable behavior of children or the problems of the elderly and handicapped, or failure of motorists to yield to pedestrians and/or bicycles within a crosswalk. Pedestrian volumes, as such, should not be the only criteria for prohibiting turns on red.
7. Education and enforcement play a significant role in the benefits and safety of right turns on red. The public needs to be educated concerning the benefits of right turns on red and their responsibilities when making this maneuver. Enforcement is important to ensure that the turns are made *after stopping* and that the necessary prohibitions are being observed.

Figure 1. ITE Technical Committee 4A-17 recommendations for RTOR.

Source: Reference [3]

Warrant No.1 - Sight Distance

This warrant allows for RTOR prohibition when "sight distance to vehicles approaching from the left is inadequate." The measurement of sight distance should be made from the stop line (if one is present) or from the edge of the curb line. The determination of adequate sight distance depends on many factors, although the speed of the approaching cross-street vehicles is of major importance relative to a RTOR vehicle.

Several specific sight distance values have been recommended and/or used as critical values for use in prohibiting RTOR. McGee [4] recommended sight distance values of 120 feet (36 m) for 20 mph (32 kph) speeds to as much as 410 feet (123 m) for 55 mph (88 kph) side street speeds, as shown in table 1. These values were later adopted by New Jersey, Washington, D.C., Montgomery County, Maryland, and possibly other agencies. The Kansas criteria are approximately the same, although the Kansas criteria call for not allowing RTOR on approaches with cross street speeds of above 50 mph (80 kph). Much higher sight distance criteria were developed at Purdue University based on 7.36 seconds of gap acceptance by right-turning vehicles. This translates into a critical sight distance of 217 feet (65.1 m) for 20 mph (32 kph) vehicle speeds to a maximum of 596 feet (178.8 m) for 55 mph (88 kph) speeds. These criteria were later adopted by Missouri, Indiana, and perhaps others.[5]

In applying Warrant 1, a user should consider the values given in table 1 and then select values which appear to be the most appropriate to their particular situations. The Purdue sight distance values are the most conservative (more of a safety buffer built in) than the McGee or Kansas values.

Warrant No. 2 - Geometric or Operational Characteristics

The second warrant for prohibiting RTOR is if "the intersection area has geometrics or operational characteristics which may result in unexpected conflicts". The interpretation of this warrant could cover a wide range of possibilties. Based on previous research and agency experience with RTOR, some of the geometric and operational conditions which may be associated with RTOR conflicts or other problems include:

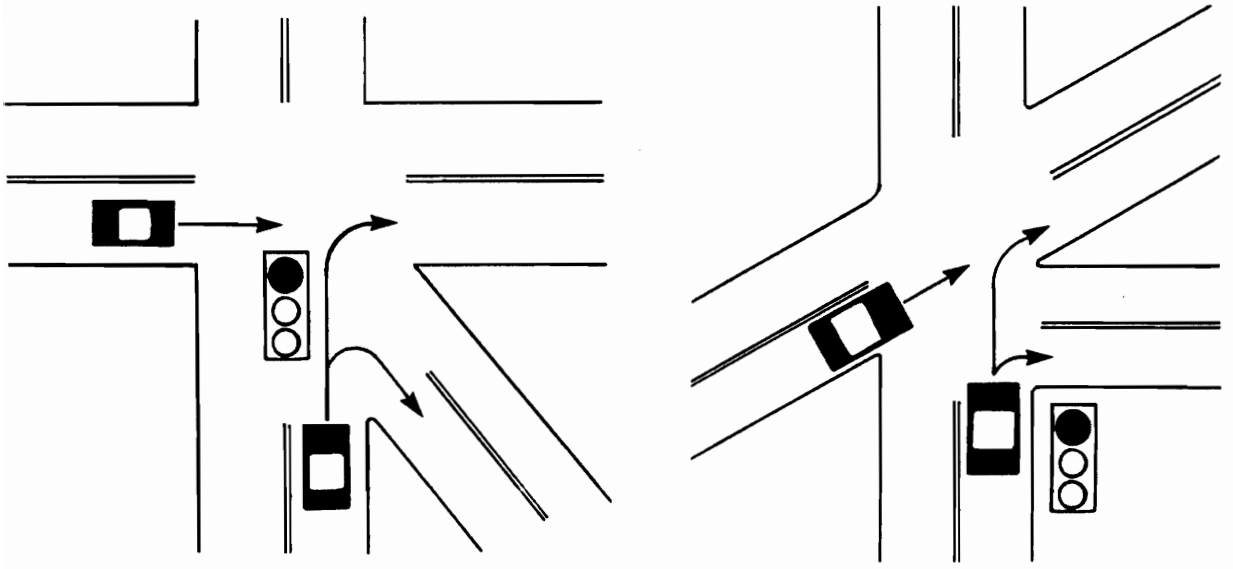
Table 1. Values of critical sight distance recommended in previous studies.

Cross Street Speed Limit (MPH)	Recommended Critical Sight Distance Values (feet)		
	McGee and Others	Kansas	Purdue and Others
20	120	---	217
25	150	140	271
30	190	175	325
35	220	215	379
40	270	260	434
45	320	310	488
50	360	370	542
55	410	*	596

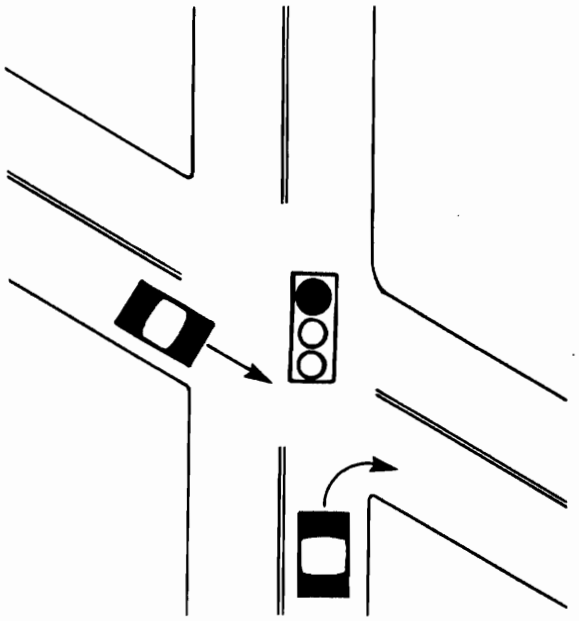
* Kansas recommends that RTOR not be allowed where cross-street traffic exceeds 50 mph (80 kph).

Note: 1 ft = 0.3 m
1 mph = 1.6 kph

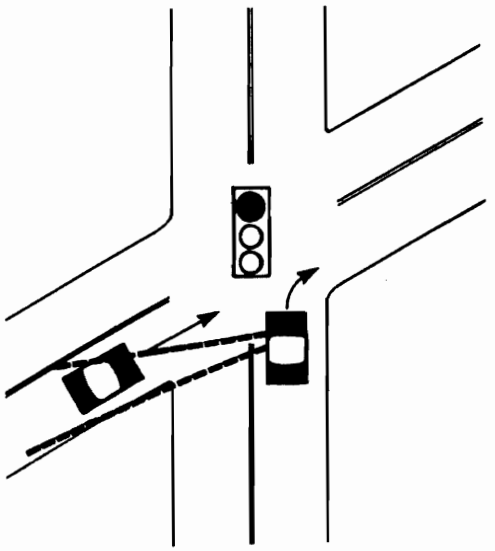
1. Geometric characteristics:
   - Intersections with five or more approaches - This may create driver confusion and/or conflicts relative to a RTOR maneuver (see sketches below).



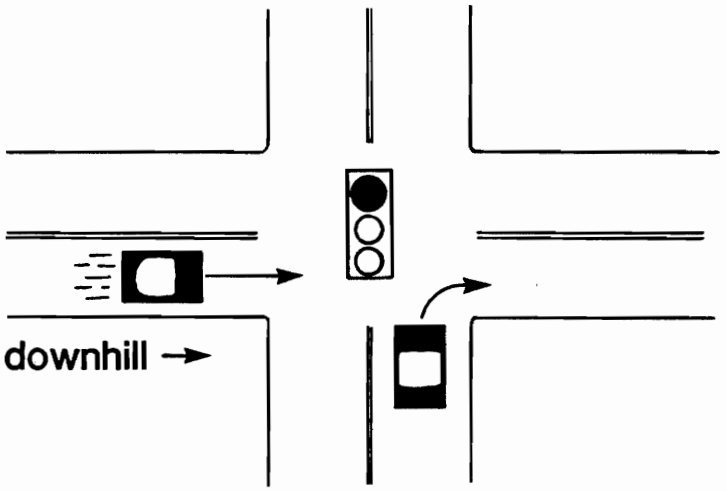
   - A narrow lane to turn into and/or a turn radius of sharper than 90° - A difficult right turn maneuver may result for RTOR vehicles (see sketch below).



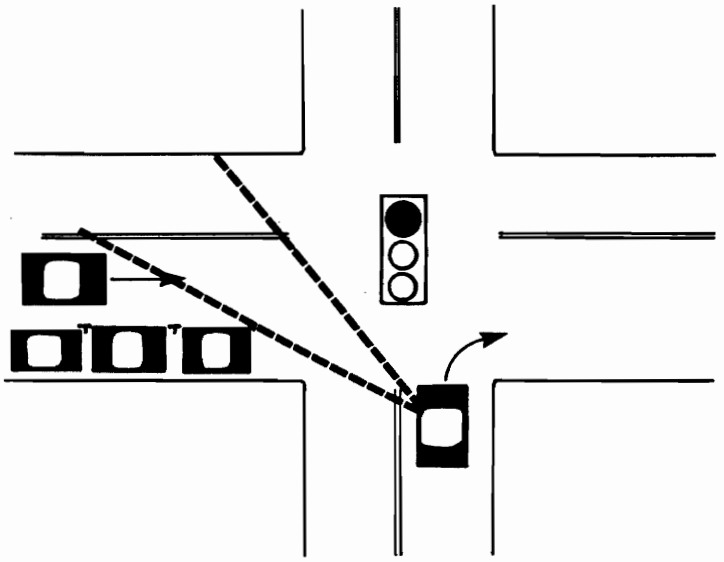
- A right turn with an angle of considerably more than 90° - This may create a sight problem, since the RTOR motorists must look back behind them to see oncoming cross-street traffic (see sketch below).



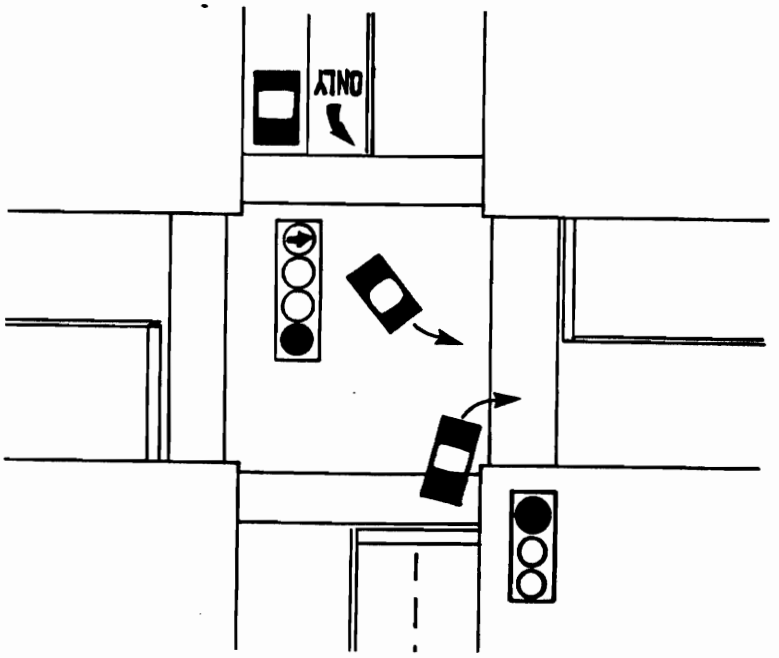
- Steep downgrade for oncoming cross-street traffic - If a RTOR vehicle turns in front of a "downhill" cross-street vehicle, it would be more difficult for a cross-street vehicle to stop (see sketch below).



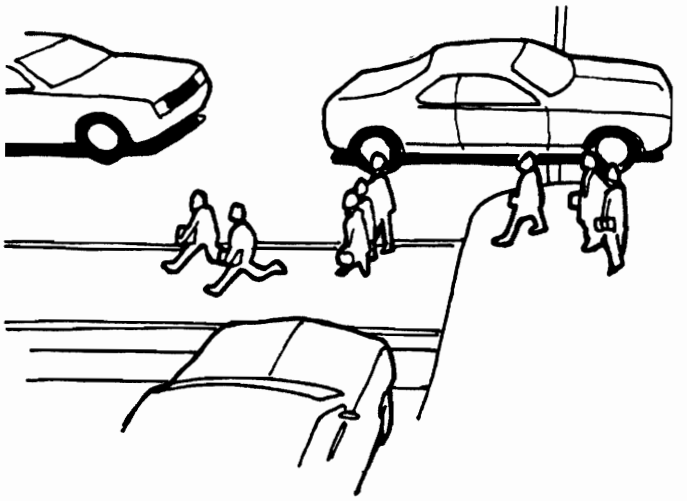
- Vehicles parked on the side street which cause a restricted sight distance (see sketch below and previous discussion of sight distance).



2. Operating characteristics:
   - Exclusive left-turn signal phase - An exclusive left-turn phase for opposing traffic could be unexpected by the RTOR motorist (see sketch below).



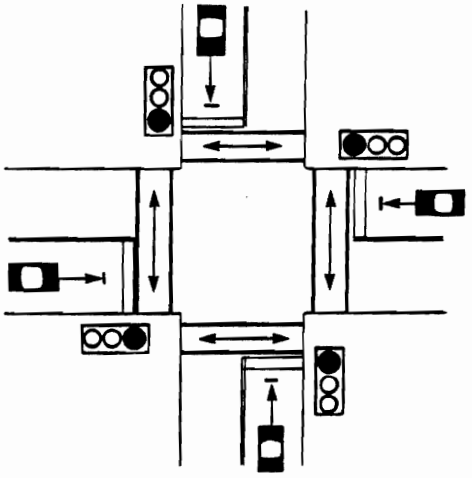
- High pedestrian volumes - This could result in conflicts between RTOR vehicles and pedestrians (see sketch below).



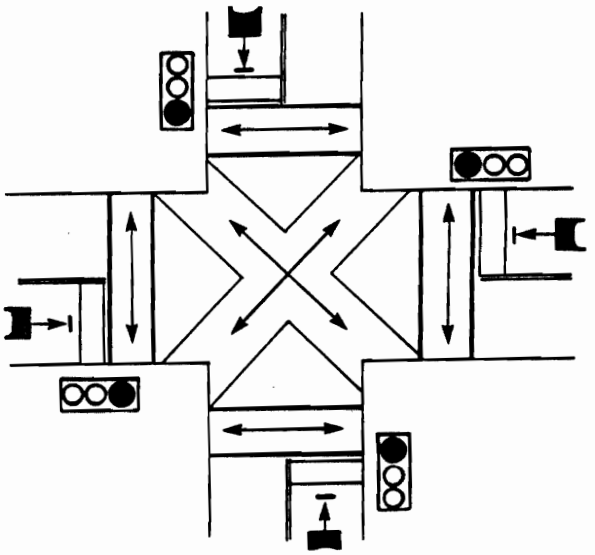
- Exclusive pedestrian signal phase - At intersections with exclusive pedestrian phases, RTOR should be prohibited (see discussion of Warrant No. 3).
- Complex multi-phase signal control - This could include split signal phasing, lagging left-turn intervals, separate right-turn phasing, or others.
- High vehicle approach speeds - Some agencies have chosen to prohibit RTOR at sites with high speeds of cross-street traffic (i.e., > 50 mph, 80 kph).

Warrant No. 3 - Exclusive Pedestrian Phase

The third warrant for RTOR prohibition stipulates that RTOR may be prohibited at intersections where there is an exclusive pedestrian phase. An exclusive pedestrian signal phase refers to the signal timing which provides a separate interval for the exclusive crossing of pedestrians, where all traffic signals have a red indication and pedestrian signals have a WALK (in the steady mode) message (see sketch below).



One type of exclusive pedestrian phasing is referred to as Scramble or Barnes Dance timing, where diagonal pedestrian crossings are also permitted. This crossing scheme is illustrated below with arrows illustrating the allowed pedestrian movements.



Allowing RTOR would defeat the basic purpose of exclusive pedestrian phasing and create an unexpected hazard to pedestrians.

Warrant No. 4 - Pedestrian Conflicts

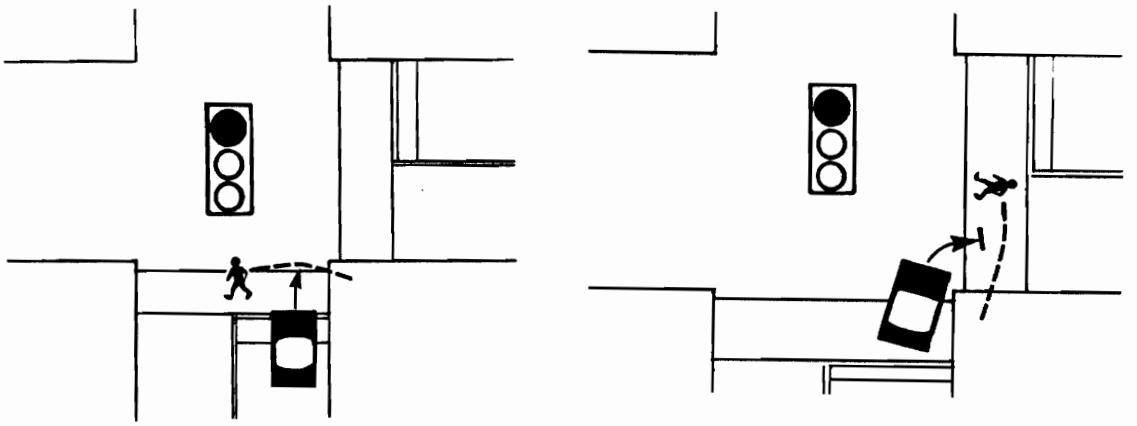
The prohibition of RTOR may also be considered if "significant pedestrian conflicts are resulting from RTOR maneuvers". Specific types of RTOR

and RTOG conflicts were defined and measured in a recent study by Zegeer and Cynecki.[1]

The basic types of RTOR conflicts for which data may be collected are:

1. RTOR Pedestrian Conflict - A RTOR vehicle interacts with a pedestrian such that either the pedestrian or RTOR vehicle must stop, speed up, or change direction to avoid a collision. A RTOR pedestrian conflict may occur in either the near or far crosswalk, as illustrated in figure 2. Note that a RTOR pedestrian conflict in the far crosswalk may result when a pedestrian crosses against the light (i.e., during the DONT WALK interval). Specific types of RTOR pedestrian conflicts are discussed below:

   - Vehicle Hesitation (VH) - Vehicle slows or stops to avoid hitting a pedestrian while executing a RTOR maneuver (see sketches below).



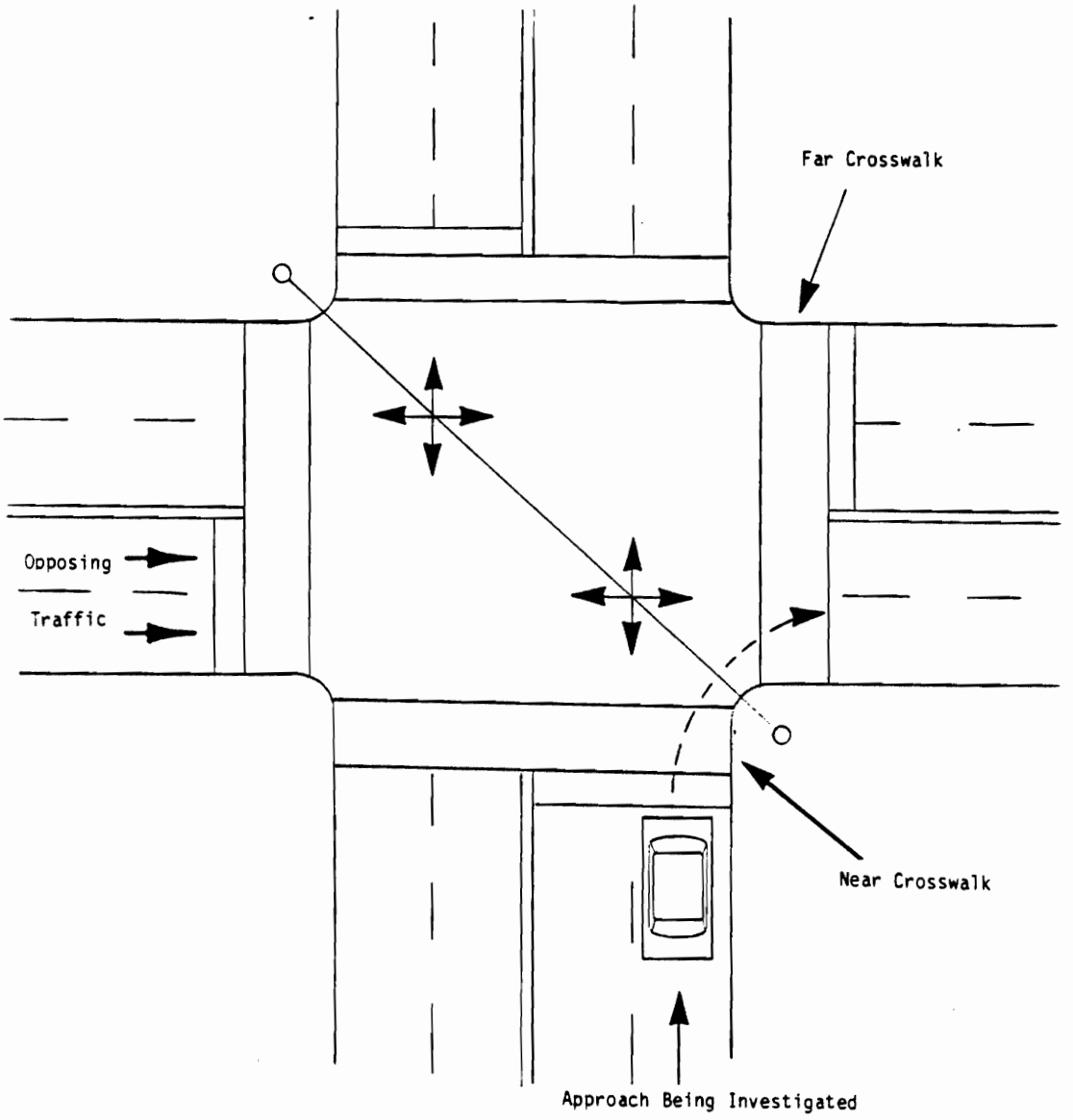
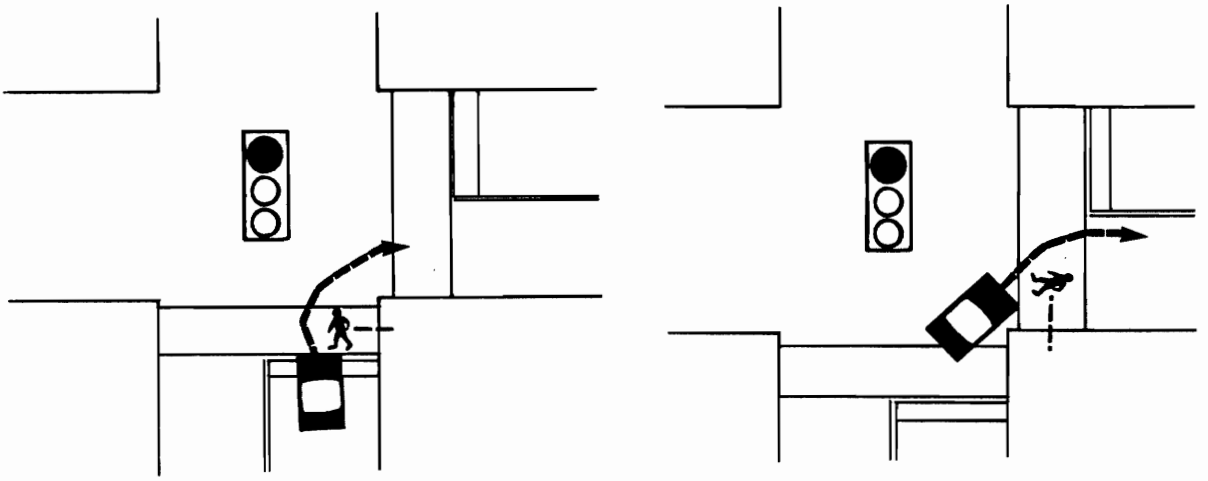
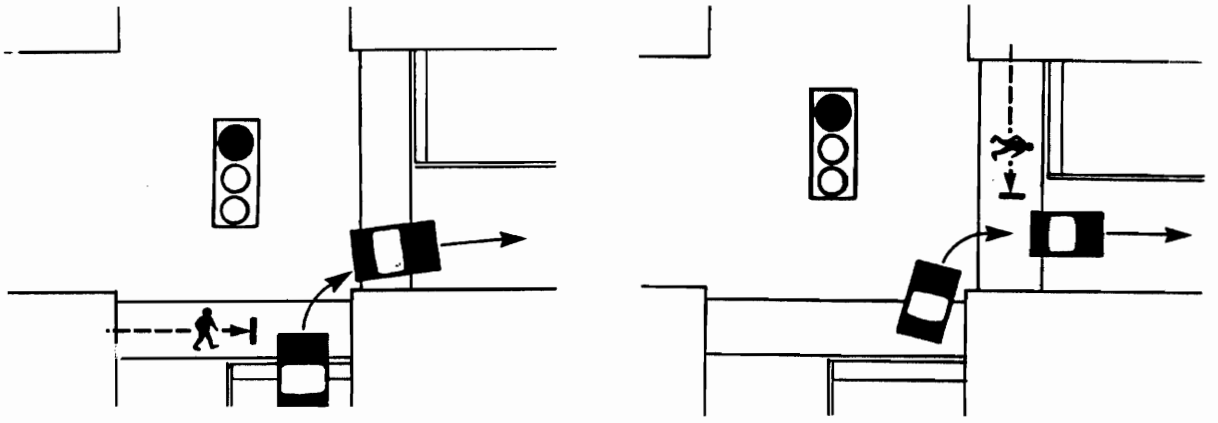


Figure 2. Illustration of the near and far crosswalks.

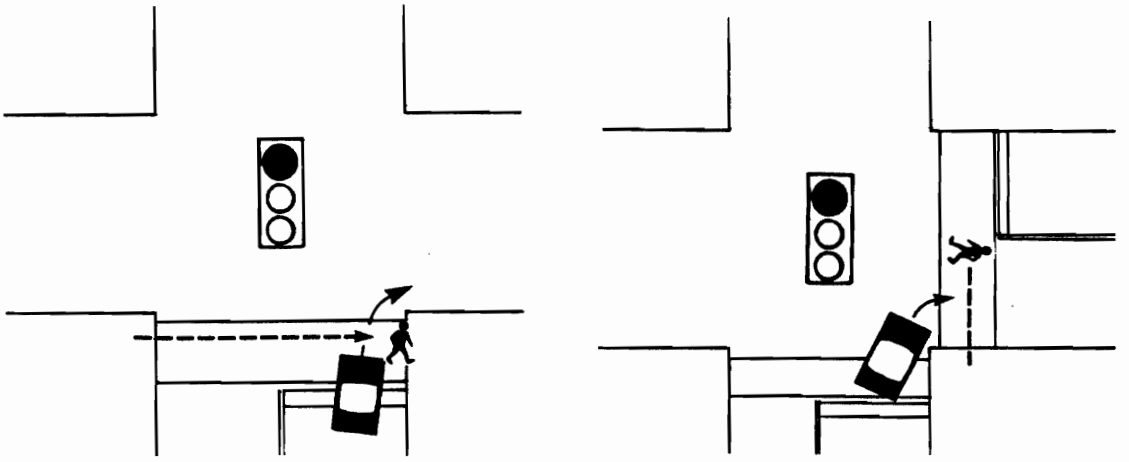
- Vehicle Swerve (VS) - Vehicle swerves to avoid hitting a pedestrian (see sketches below).



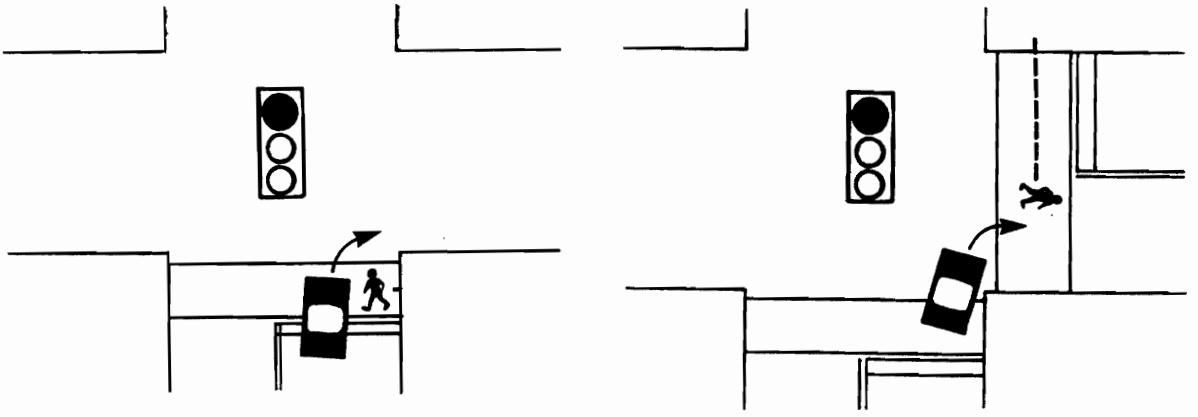
- Pedestrian Hesitation (PH) - Pedestrian slows, stops, or reverses direction of travel to avoid a collision (see sketches below).



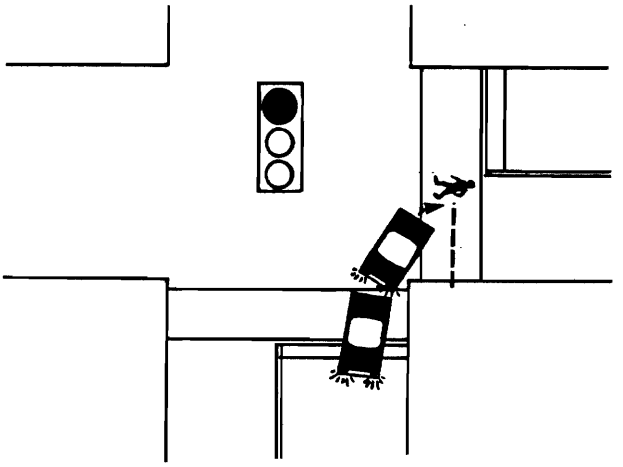
- Pedestrian Run (PR) - Pedestrian increases walking speed or runs to avoid a collision (see sketches below).



2. Interaction (I) - Neither the vehicle nor the pedestrian reacts, but the pedestrian is in a moving lane and is within 20 feet (6 m) of the RTOR vehicle (see sketches below).



3. Secondary Conflicts (SC) may also be collected, if desired. These occur when a vehicle is forced to brake or weave as a result of a previous RTOR conflict (see sketch below).



Secondary conflicts are usually rare, and may be of minor importance compared to the primary conflict types.

Conflict data are commonly collected in 10-minute intervals, as shown in figure 3. This may also include such information as:

- Start time and end time of the data collection period (military time).
- Approach (northbound, eastbound, etc.).
- The pedestrian volume on the near and far crosswalk.
- The number of right-turn-on-green (RTOG) vehicles.
- The number of right-turn-on-red (RTOR) vehicles.

Whenever a pedestrian-related conflict occurs, the observer should place a symbol (VH, VS, PH, PR, or I) in the corresponding box. When a conflict occurs with cross-street traffic, the observer should place a mark in the box. Conflict data can then be totaled for each conflict type.

RTOR CONFLICTS AND VOLUME DATA FORM.

CITY: Washington, D.C. OBSERVER: MB

LOCATION: [redacted] WEATHER: Sunny 60°

DATE: 5-27-83

VH = Vehicle Hesitation
VS = Vehicle Swerve
PH = Pedestrian Hesitation
PR = Pedestrian Run
I = Interaction (within 20 feet)

Period	Time		Approach	Right Turn on Green					Right Turn on Red				Pedestrian Volume	
				Arrive on Green	Arrive on Red		Conflict With Pedestrian		No Conflict	Conflict With Traffic	Conflict With Pedestrian			
	From	To			RTOR Opportunity	No RTOR Opportunity	Near X-Walk	Far X-Walk			Near X-Walk	Far X-Walk	Near X-Walk	Far X-Walk
1	7:30	7:40	WB	14	—	—	—	PR I-2 VH	—	—	—	—	33	23
2	7:40	7:50	WB	10	1	—	—	I-6 VH	3	—	I-2	—	30	36
3	7:50	8:00	WB	19	3	—	—	VH-4 I-8	1	—	—	—	36	24
4	8:16	8:26	NB	9	1	—	—	VH-5 I-5	2	—	—	PR	67	47
5	8:26	8:36	NB	3	1	—	—	VH-3 I-5	3	—	—	—	65	56
6	8:36	8:46	NB	9	3	—	—	VH-5 I-6	—	—	—	—	73	50
TOTAL				64	9	0			9	0			304	236

Figure 3. RTOR conflicts and volume data form.

The next issue involves the number of RTOR conflicts per hour which may be considered to be "significant", (i.e., corresponds to an unsafe level). While there is no specific number that should be considered as an absolute cutoff value for all situations, some information is available for RTOR pedestrian conflicts. In the 1985 study by Zegeer and Cynecki [1], RTOR conflict data were collected for 111 approaches with RTOR allowed and 95 approaches with RTOR prohibited. Conflict data were collected for 4 to 8 hours per approach, which included both peak and off-peak periods.

A summary of the peak hour conflict levels at RTOR-allowed sites are given in table 2, separately for RTOR pedestrian conflicts and total RTOR conflicts (i.e., pedestrian plus cross-traffic conflicts). These levels are expressed in terms of percentiles, from 0 to 100. For example, the RTOR pedestrian conflicts per intersection approach ranged from 0 to 20 per peak hour. Ninety percent of the locations had peak hour conflicts of six or less, fifty percent of the locations had two or less conflicts, etc. Thus, a user may wish to select a percentile level to use as a basis, and then use the corresponding conflict level as a critical value. For example, if a user considers the top 5 percent of sites (i.e., 95 percentile level) as candidates for RTOR prohibition, then a value of 7 RTOR pedestrian conflicts per hour may be selected as a critical level.

The same kind of analysis may be used to analyze total RTOR conflicts (i.e., includes pedestrian plus cross-street conflicts). Critical values may be selected in the same way based on selected percentile levels. A 95 percentile level of total RTOR conflicts would be 11 per peak hour. The determination of what percentile level to select is strictly a decision of the user, and should be based on the user's perception of the effectiveness of NTOR signs on local intersections. A value of 80 to 95 percent would be a reasonable range, which would correspond to 4 to 7 RTOR pedestrian conflicts per hour, or 6 to 11 total RTOR conflicts per hour.

Note that the actual numbers of RTOR conflicts with cross-street traffic and pedestrians will vary widely, depending on such factors as:

Table 2. Summary of conflict distributions at RTOR-allowed sites.

Level	Number of Conflicts per Peak Hour*	
	RTOR-Pedestrian Conflicts	Total RTOR Conflicts (Pedestrian & Cross Traffic)
0 Percentile (Minimum Value)	0	0
10 Percentile	0	0
20 Percentile	0	1
30 Percentile	1	2
40 Percentile	1	2
50 Percentile	2	3
60 Percentile	2	3
70 Percentile	3	5
80 Percentile	4	6
90 Percentile	6	10
95 Percentile	7	11
100 Percentile (Maximum Value)	20	32

* Values exclude interactions and secondary conflicts.

- The volumes of cross-street traffic and pedestrians at the site.
- The number of RTOR vehicles per hour.
- The number of RTOR motorists that make a full stop before making a RTOR.
- Signal timing, roadway geometrics, and other site conditions.

The use of table 2 assumes that the locations of interest represent a similar range of conditions as the sites used in the research study, which consisted of sites in urban and urban fringe areas in the cities (and surrounding areas) of Detroit, Michigan; Washington, D.C.; and Austin and Dallas, Texas. Most of the intersections were selected in areas with some pedestrian activity.

The above conflict distributions are intended to be a starting point for initial use. The user should first test the conflict levels based on their own local conditions for numerous sites. If the conflict levels at the agency's sites differ substantially from table 2, then the agency should develop their own critical conflict levels for use based on local conditions and conflict patterns.

Warrant No. 5 - RTOR Accidents

The fifth warrant for RTOR prohibition specifies "More than three RTOR accidents per year have been identified for the particular approach". There are several issues that must be remembered when applying this warrant:

1. Many agencies do not currently have a separate "category" or space on the accident report form for a police officer to indicate whether the accident involved a RTOR vehicle. In some cases, an officer may determine that a vehicle was turning right on red, and so indicate that in the written description of the accident.
2. Just because an accident report form provides a separate space for indicating a RTOR involvement, this does not guarantee that all RTOR-related accidents will be recorded. When a police officer arrives at the accident scene, he may not be able to determine if

a RTOR vehicle was involved. Conflicting statements by involved motorists or witnesses may further confuse the issue. A RTOR motorist may claim that the light was amber or green, for example.

3. The actual definition of a "RTOR accident" may also be open to question. The MUTCD warrant may be assumed by some people to apply only to an accident between a RTOR vehicle and another vehicle or a pedestrian. However, a RTOR maneuver could also result in other "indirect" accident types. For example:
   - A through motorist (in an adjacent through lane) observes a RTOR vehicle and, without looking at the signal, assumes that the light has changed to green. The through motorist runs the light and is struck by a cross-street vehicle.
   - A vehicle makes a RTOR in front of an oncoming cross-street vehicle, causing the cross-street vehicle to make an abrupt stop or change lanes. The cross-street vehicle is involved in a resulting rear-end or sideswipe accident.
   - A vehicle starts to make a RTOR and stops abruptly when the driver notices a pedestrian or an oncoming cross-street vehicle. The aborted RTOR maneuver results in a rear-end collision from a trailing vehicle.

These represent only a few of the other accident conditions which may be indirectly associated with a RTOR maneuver. The determination of a RTOR vehicle involvement in such accident situations may not be feasible.

When trying to determine whether one or more intersection approach meets the accident warrant for RTOR prohibition (i.e., three or more RTOR accidents per approach per year), the following actions should be taken if a RTOR designation is NOT on the accident report form:

1. If not currently on the accident report form, consider adding a separate "space" for the police officer to indicate whether the accident involved a RTOR vehicle. Until the RTOR-related information is available and coded on the computerized accident file, manual sorting and review of accident report forms is required.

2. Accident report forms should be reviewed carefully for intersections which are suspected as having a RTOR-related accident problem. The review of more than 1 year (i.e., 3 to 5 years) of accident data is desirable, if possible, to determine the long-term experience with RTOR-related accidents.
3. After reviewing all accidents at selected sites, summarize accidents by severity and intersection approach based on:
   - RTOR accidents involving cross-street vehicles.
   - RTOR accidents involving pedestrians.
   - Accidents related to RTOR vehicles but not directly involving them.
   - Other pedestrian accidents at the intersection.
   - Other basic accident types at the intersection (i.e., rear-end, right-angle, etc.).
4. Determine the number of RTOR-related accidents for each approach in the past year and also for preceding years, if possible. A sample accident summary form is illustrated in figure 4 for RTOR accidents.
5. Compare the RTOR accidents with the MUTCD warrant (three or more per year per approach) and determine whether the warrant is met.
6. Analyze the other pedestrian accidents at the intersection, and particularly those resulting from a right- or left-turn-on-green.
7. If there is a definite problem with pedestrian accidents in general, prohibiting RTOR may not necessarily solve the pedestrian accident problem. In fact, a RTOR prohibition in some cases may simply shift the problem from the red phase to the green phase for a particular approach. Thus, if a pedestrian safety problem is observed, the user should also consider more general types of pedestrian-related safety treatments in addition to those discussed in Chapter III. The "Model Pedestrian Safety Program" Users Manual [6] should be used in such cases along with other pedestrian safety reports.

RTOR ACCIDENT SUMMARY FORM

City: Anytown, Michigan Intersection: 1ST at Main

Time Period 1/1/82 to 12/31/84 Approach: All

Accident Type	Accident Severity					Total
		No. Injury Accidents (No. of Injuries)				
	PDO	A	B	C	Fatal	
RTOR with Cross-Traffic	1	0	0	1	0	2
RTOR with Pedestrians	0	1	0	0	0	1
RTOR Indirect Involvement	0	0	1	0	0	1
RTOG with Pedestrians	0	0	2	0	0	2
Other with Pedestrian	0	2	1	0	0	3
Rear-end	18	0	1	2	0	21
Right-Angle	9	3	5	2	1	20
Other	8	0	1	1	0	10
Total	36	6	11	6	1	60

Figure 4. RTOR accident summary form.

8. If a definite RTOR accident problem is found, the user should consider the following three options:
   - Prohibit RTOR on the approach (if it is determined that RTOR prohibition will solve the problem without creating a RTOG problem).
   - Consider other RTOR-related countermeasures, as discussed in Chapter III.
   - Consider other more general types of countermeasures, such as pedestrian-related safety treatments, in cases of an overall pedestrian accident problem.

If a highway agency has a computerized accident database which contains coded information on RTOR-related accidents, a computer listing should be generated of the locations with one or more RTOR-related accidents. Then, those intersections should be ordered based on the frequency of RTOR accidents. This list should then be used as a starting point for further investigation of sites. In particular, accident report forms should be obtained for the locations with the most identified RTOR accidents (perhaps those with one or more identified RTOR accidents). Then, the user should follow steps 3 through 8, as discussed above.

Warrant No. 6 - Significant Crossing Activity

The sixth warrant specifies that RTOR may be prohibited if "there is a significant crossing activity by children, elderly, or handicapped people". This warrant is useful to provide consideration of RTOR prohibition for the safety of children, elderly, or the handicapped. In this regard, the ITE Committee 4A-17 [3] made the following recommendation:

> Universal prohibition at school crosssings should not be made but rather restrictions should be sensitive to special problems of pedestrian and/or bicycle traffic, such as the unpredictable behavior of children or the problems of the elderly and handicapped, or failure of motorists to yield to pedestrians and/or bicyclists within a crosswalk. Pedestrian volumes, as such, should not be the only criteria for prohibiting turns on red.

This recommendation suggests that RTOR prohibitions should not be automatically installed in school zones, but only when a need exists, such as if motorists commonly fail to yield to pedestrians. In fact, the over-use or misuse of a traffic restriction, such as RTOR prohibition when not justified, may likely lead to a high rate of motorist violations of the restriction.

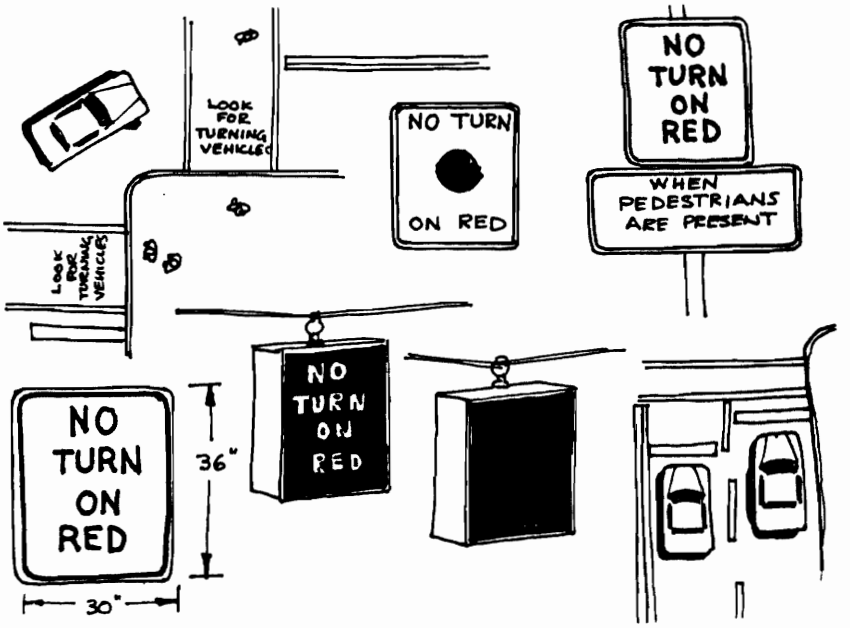
Another issue pertains to the volumes of pedestrians which may be appropriate for consideration of RTOR prohibition. While such volume levels should, no doubt, depend on the local conditions (i.e., for local driver and pedestrian behavior), one recent study [1] found that the combination of 26 or more RTOR vehicles per hour with 250 or more pedestrians (near plus far crosswalk) per hour was associated with the highest incidence of pedestrian conflicts for the data available. The authors suggested these values as deserving of consideration for RTOR prohibition. In terms of the elderly and handicapped, the presence of an intersection near nursing homes, retirement homes and communities, etc., are prime candidates for possible RTOR prohibition.

It should be remembered that the liberal prohibition of RTOR does not guarantee increased safety. In fact, prohibition of RTOR could cause:

- A shift of the problem from RTOR to RTOG on an approach.
- The incidence of high motorist violations of the RTOR prohibitions if motorists are unjustly delayed for no apparent reason (i.e., motorist has a clear sight distance with a long red interval and few or no pedestrians or cross-street traffic).

On the other hand, the lack of RTOR prohibitions where needed could also create a safety hazard, particularly to pedestrians. Before prohibition signs are placed on intersection approaches, however, consideration should also be made of other types of countermeasures, as discussed in the next chapter.

CHAPTER III - COUNTERMEASURES



The most common countermeasure for RTOR-related problems that has been used to date has been to prohibit RTOR on an approach. Total as well as part-time prohibitions have been used. Countermeasures related to RTOR accidents may be used to accomplish several specific objectives, as follows:

- Reduce motorist violations of NTOR signs.
- Reduce the number of drivers that fail to come to a full stop before turning right on red at locations where RTOR is allowed.
- Minimize the potential hazard to pedestrians and cross-street traffic resulting from motorists turning right on red (either legally or illegally).
- Improve conditions at the approach to allow motorists to make a safer RTOR maneuver.

Zegeer and Cynecki [1] developed 30 possible countermeasures related to RTOR accidents, as shown in table 3. These were summarized into five general categories:

- Signs (12 countermeasures).
- Signals (6 countermeasures).
- Pavement markings (3 countermeasures).
- Design treatments (5 countermeasures).
- Others (4 countermeasures).

The countermeasures discussed in this User's Manual primarily involve physical roadway improvements, such as: (1) signing options, (2) signal modifications, (3) pavement markings, (4) design changes, and (5) other treatments (i.e., adding intersection lighting, removing roadside clutter, etc.). The use of selective traffic enforcement and public (driver or pedestrian) education programs are also recognized as potential treatments for RTOR problems. In fact, good education and enforcement programs are essential ingredients which must be used in conjunction with engineering improvements in striving for an effective traffic safety program. It is recognized that changes in local or national laws regarding RTOR could also impact RTOR safety and operations. A comprehensive process for selecting, implementing, and evaluating RTOR-related countermeasures is discussed in the following section.

PROCESS FOR COUNTERMEASURE SELECTION AND IMPLEMENTATION

The selection of appropriate traffic-engineering treatments for a RTOR-related problem requires a comprehensive analysis. Chapter II discussed considerations which are helpful in deciding whether a NTOR sign is warranted based on current MUTCD guidelines. However, as discussed earlier, RTOR prohibition is not a cure-all solution to RTOR problems, and other types of countermeasures should be considered prior to full prohibition of RTOR. Even if RTOR prohibition is warranted, various countermeasures may be considered to insure better compliance of the NTOR signs (i.e., larger NTOR sign, double NTOR signs, use of selective enforcement, variable message or time restricted NTOR signs, etc.).

Table 3. Countermeasures developed for RTOR.

Category	Device	Description	Comments
SIGNS	1. 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 right-turn-on-red maneuver.	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 non-uniform application of RTOR prohibitions. Since 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.
	2. Partial prohibition of ROTR for certain lanes or during specific times of the day.	Install special signs that prohibit RTOR for certain times (7 a.m. to 7 p.m.), days (school days), conditions (when children present), seasons (Sept. to June), lanes (NTOR - except curblane) or other factors.	Since conditions may change at a site (by time of day or day of week, etc.) 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.
	3. YIELD TO PEDESTRIAN sign.	Install a yield sign directed at turning motorists advising them to yield right-of-way to pedestrians.	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.
	4. Illuminate NO TURN ON RED sign.	Illuminate the NTOR sign for increased visibility. This could be accomplished using an illuminated case sign (internal source) or external lighting.	Designed for areas where there is a nighttime RTOR-related problem and/or where no intersection lighting exists.
	5. Larger NO TURN ON RED sign.	Use a NTOR larger than the current MUTCD standard of 24x30 inches or 24x24 inches (60x75-cm or 60x60-cm).	NTOR sign should ideally be placed near the signal. Applicable for near signal placement when the signal is located on the far side of a wide street or is otherwise difficult to read. May be particularly helpful in cities or locations where overhead sign placement is not possible.
	6. Near-signal placement of NO TURN ON RED sign.	Install NTOR sign on span arm, span wire or signal pole near the signal head where motorist tends to look.	The 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.
	7. Redundant NO TURN ON RED signs.	Install two or more NTOR signs on both posts (near or farside) and overhead to increase visibility of sign.	While this countermeasure is applicable for some locations with high violation rates, high conflict rates, or poor sign visibility, redundant sign placement should be minimized.
	8. RIGHT TURN ON RED AFTER STOP sign.	Install a sign which reminds motorist to come to a complete stop before turning on red.	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-

Table 3. Countermeasures developed for RTOR (continued).

Category	Device	Description	Comments
SIGNS	9. NO TURN ON RED sign with red ball.	Install a modified NTOR sign with a red ball in the center to draw attention to the sign.	A sign with a red ball may catch the motorist's eye better. This device is currently used in some cities.
	10. Advance warning of NO TURN ON RED.	Install a sign in advance of the intersection to warn motorists that there is a RTOR prohibition at the next intersection.	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 have minimal effect for those stopped at the signal.
	11. Electrical/mechanical variable message NO TURN ON RED sign.	Install signs which can display different messages for different signal intervals, times of day, or days of week, etc.	This device has two applications: (1) prohibit RTOR during portions of the day having high pedestrian volumes or cross-street volumes, or (2) 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.
	12. PEDESTRIANS WATCH FOR TURNING VEHICLES warning sign.	Install a warning sign directed toward pedestrians to warn of turning vehicles. This device supplements the pedestrian signals.	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	13. Special pedestrian signal display (WALK WITH CARE).	Use a 3-head signal having a WITH CARE or other indication in yellow displayed during the WALK interval to warn of possible conflicts (i.e., WALK WITH CARE).	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, since 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.
	14. 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 multi-phase operation.	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 shown to be related to lower pedestrian accidents, also increases delay and congestion to pedestrians and motorists.

Table 3. Countermeasures developed for RTOR (continued).

Category	Device	Description	Comments
SIGNALS	15. Traffic actuated signal.	Use presence detectors to determine the right-turn demand and actuated signals to accommodate the demand and reduce the number of RTOR's.	May be applicable to some intersections with heavy right-turn demand.
	16. Remove unwarranted traffic signals.	Remove unwarranted signals and replace with other types of traffic control.	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. While this may have the benefit of improving flow, reducing operating costs, and saving energy, pedestrians must cross the street without signal assistance.
	17. 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.	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 a RTOR. This would require an extra signal lens. It may not convey a clear and simple meaning to all motorist and would require FHWA approval prior to use. It is currently not in the MUTCD.
	18. NO TURN ON RED signal installed in pedestrian signal hardware.	Install an illuminated signal directed at motorists in pedestrian signal hardware to prohibit RTOR.	This device uses existing pedestrian signal hardware (with a different lens) to display a blank-out or a NO TURN ON RED indication to motorists. Applicable for partial RTOR prohibitions. Blank-out device minimizes confusion during RTOR allowed periods.
PAVEMENT MARKINGS	19. Relocate crosswalk further from intersection.	Move the crosswalk further from the intersection to increase visibility of pedestrians.	Moving the stop bar and crosswalk further from the intersection may discourage RTOR's 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.
	20. Offset or angled stop bars.	Angle or offset the stop bar so that drivers in the middle lanes are stopped further back from the intersection than right-turn vehicles in the curb lane.	For sites where RTOR is allowed. Applicable to multi-lane approaches where there is a high incidence of truck and bus traffic which 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.
	21. Pavement marking.	Pavement marking message in crosswalk to remind pedestrians to watch for RTOR vehicles. (i.e., LOOK FOR TURNING VEHICLES").	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.

Table 3. Countermeasures developed for RTOR (continued).

Category	Device	Description	Comments
DESIGN	22. Pedestrian barriers.	Install barriers to channelize pedestrians to the crosswalk thereby minimizing the conflict area.	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.
	23. Pedestrian overpass/underpass.	Grade separation of pedestrians and motorists eliminating conflicts.	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.
	24. Far side bus stops.	Allow buses to stop to drop-off and pick up passengers only after crossing the intersection.	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.
	25. Eliminate parking near the intersection.	Remove on-street parking near the intersection on either site or both sides of the street.	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.
	26. Separate right-turn lane.	Provide a separate lane for right-turns.	Applicable to sites with high volumes of right-turn traffic. Reduces intersection delay and increases capacity. Right-of-way may not be available in densely developed areas to accommodate a separate turn lane.
OTHER	27. Intersection lighting.	Illuminate the intersection to provide better visibility of pedestrians at night.	Applicable to locations with high nighttime pedestrian volumes, and nighttime safety problems exist. May reduce other types of nighttime accidents at the intersection and may be useful in reducing crime at night.
	28. Education campaign.	Educate the public using various forms of media to increase awareness and to teach proper understanding of RTOR.	Educational compaigns 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 a lasting impact. Difficult to evaluate, especially relative to RTOR.
	29. Clear roadside clutter.	Romove roadside items to increase motorist visibility of pedestrians and traffic control devices.	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.
	30. 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.	Enforcement or police presence near the intersection may reduce other violations. Effectiveness may diminish once the police leave. Since manpower is limited in most agencies, police time may be better spent in other areas of traffic enforcement or crime protection.

Where RTOR is allowed, the RTOR maneuvers may be resulting in conflicts and/or vehicles not making a full stop before turning right on red. In such cases, countermeasures may be considered to reduce the problem, such as offset stop bars, changes in signal timing, and others. Thus, RTOR-related countermeasures may be aimed at intersection approaches either where RTOR is allowed or where RTOR is prohibited.

A comprehensive approach for addressing RTOR problem locations consists of five steps, as illustrated in figure 5. These include:

- Step 1 - Identify RTOR Problem Sites.
- Step 2 - Collect and Analyze Site Data.
- Step 3 - Select Countermeasures.
- Step 4 - Install Countermeasures.
- Step 5 - Evaluate Countermeasure Effectiveness.

Note that after one or more countermeasures are installed, an effort should be made to determine their effect on violations, conflicts, and eventually on RTOR accidents (if any). The results of these evaluations can provide valuable information for improving future practices on RTOR use and countermeasure selection. The following is a discussion of each of these five steps.

Step 1 - Identify RTOR Problem Sites

A potential RTOR problem site may be identified in one or more of the following ways:

1. RTOR-related accidents have occurred which exceed some threshold value. These may involve accidents where RTOR motorists strike pedestrians or side street motorists. A threshold value of three RTOR-related accidents per approach in a year would meet the MUTCD warrant for prohibiting RTOR on the approach.
2. Complaints have been received from citizens and/or police officers about RTOR conflicts with turning vehicles, pedestrian conflicts, or pedestrian delay resulting from RTOR vehicles.

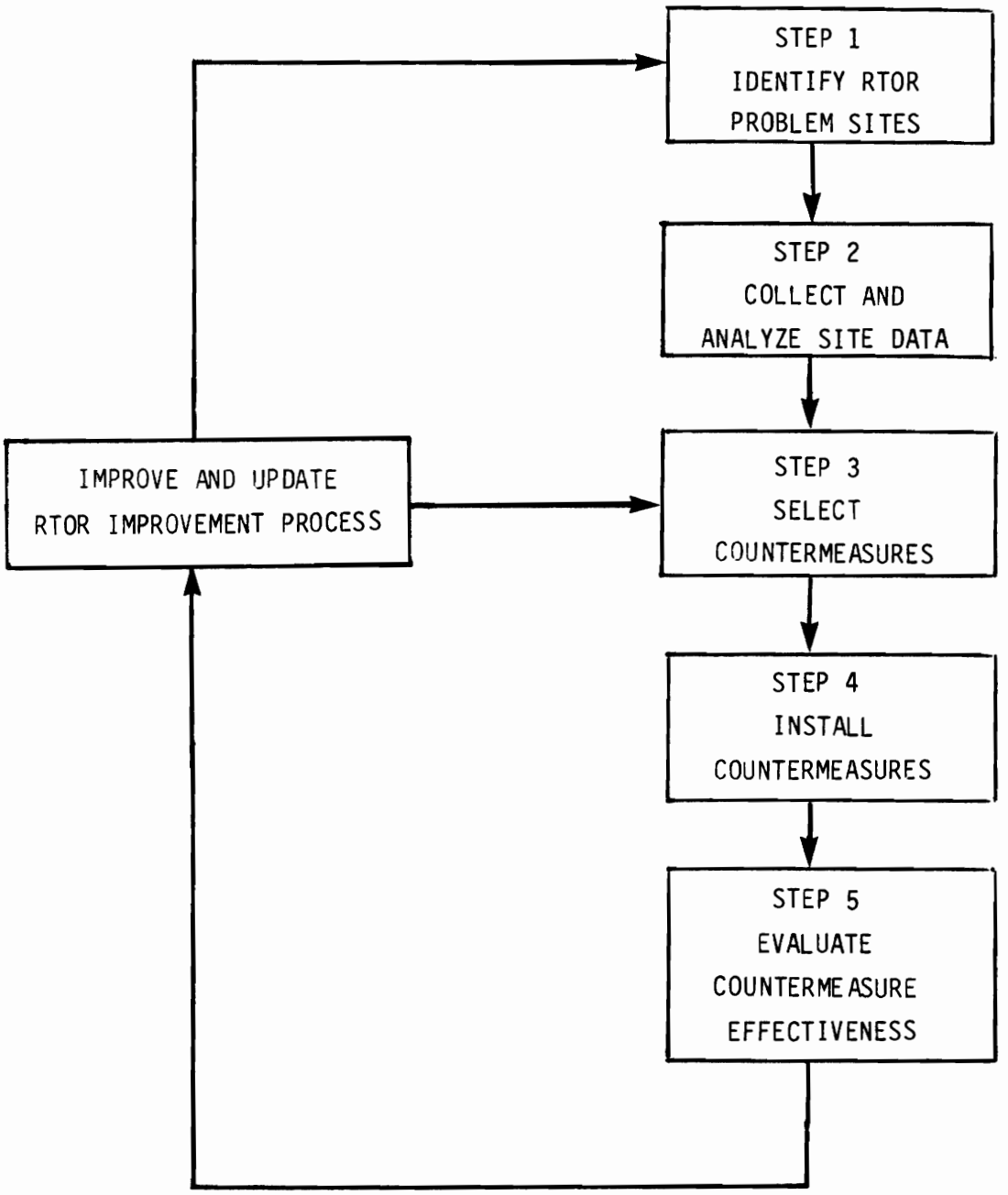


Figure 5. Flowchart of RTOR improvement process.

3. Certain geometrics exist (i.e., multi-legged intersections, high speed side streets, etc.) and/or operational conditions (i.e., high traffic or pedestrian volumes) that are associated with a potential RTOR-related problem.
4. High violations occur relative to:
    - NO TURN ON RED signs.
    - The full-stop requirement is violated at locations where RTOR is allowed.
    - RTOR motorists not yielding to pedestrians.
5. Sufficient volumes of pedestrians and/or pedestrian types (i.e., elderly, children, handicapped) exist, and/or the location is of a type (near school, recreation area, elderly homes, etc.) which may create a RTOR problem.
6. Routine site inspections by traffic engineering personnel within an agency indicate a potential RTOR problem.

Intersections may be identified as having possible RTOR problems through one of two ways:

- Systematic review of all intersection approaches, in terms of RTOR accidents, pedestrian volumes, traffic speeds and volumes, sight distance, and other criteria to select sites with RTOR-related problems.
- Consideration of individual sites as they are identified by one or more of the six methods discussed above.

While systematic reviews may be a worthwhile approach, this may not always be feasible, depending on the manpower available within a highway agency. Regardless of how a RTOR problem site is identified, an effort should be made to determine the causes of the problem, as discussed below.

Step 2 - Collect and Analyze Site Data

After an intersection or approach is identified as a possible RTOR problem site, a site survey and some data collection is needed to:

- Verify that a RTOR problem does or does not exist.
- Assess the nature and magnitude of the problem, as well as the probable cause of the problem.
- Use the analyzed information in selecting what corrective action (if any) is needed.

For each identified RTOR problem site, the following data should be collected:

1. Review accident reports at the site for the past 1 to 3 years to gain a better understanding of the nature and cause of the safety problems. Special attention should be given to RTOR-related accidents and to pedestrian accidents in general.
2. Obtain turning movement counts of right- and left-turn volumes for a.m. and p.m. peak periods. The volumes of RTOR vehicles may also be useful for RTOR-allowed sites.
3. Collect pedestrian crossing volumes for intersection approaches of concern. Thus, for a particular approach, pedestrian volumes may be collected for the crosswalks affected by a RTOR vehicle (i.e., the near and far crosswalks).
4. Conduct a site survey during critical periods. An example of such a survey form is shown in figure 6. Note that the site sketch should also be drawn to provide detailed site characteristics. For approaches where RTOR is permitted, the following information should be collected:
   - Sight distances for critical approaches should be checked, as measured from the stop bar to the drivers' left. The observed sight distance should then be compared against the critical values for various levels of speed for side-street vehicles, as given earlier in table 1.
   - RTOR-related conflicts and violations should be counted during peak periods to determine if RTOR motorists are yielding to pedestrians and side street traffic and are making a full stop before making a RTOR maneuver.
   - Signal phasing should be checked to determine phasing sufficiency, especially for pedestrian phases.

RTOR - SITE DATA FORM

INTERSECTION [redacted] AND [redacted] DATE 3-15-83

CITY/COUNTY Warren / Macomb STATE Mich

OBSERVER B.C.

AREA TYPE

Rural ____
Residential ____
Commercial X
Industrial ____
CBD ____

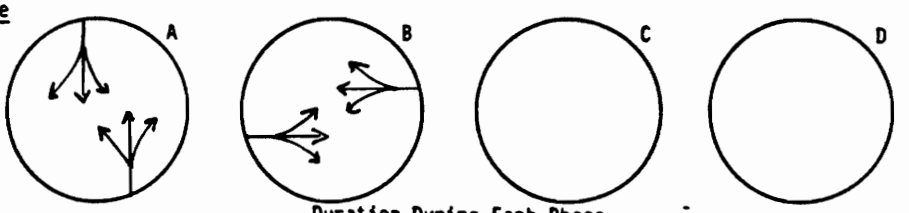
WEATHER Cloudy TEMPERATURE 40°

PAVEMENT CONDITION Good

Approach	Sight Distance	Posted Speed	Offset Stop Bar	RTOR Prohibitions	RTOR Sign Mounting
NB	>500 ft	40	5 ft	None	None
SB	>500 ft	40	5 ft	None	None
EB	>500 ft	40	5 ft	NTOR	Post
WB	>500 ft	40	5 ft	NTOR	Post

Signal Timing

Phase



Duration During Each Phase

Interval	A	B	C	D	E
Red	30	26			
Green	26	30			
Amber	4	4			
Walk					
Clearance					
DONT WALK					

Cycle Length 60

Figure 6. RTOR site data form.

- Intersection geometrics should be recorded or measured for the lane widths, turning radii, roadside clutter, and location of crosswalks (see site survey form in figure 6).
- Pedestrian-vehicle conflict data should be collected and compared with values given earlier. Critically high conflicts may indicate a need for RTOR prohibition or the use of other countermeasures.

For intersections with RTOR prohibited, (full-time or part-time) the following data should be recorded:

- The visibility and conspicuousness of the NO TURN ON RED sign.
- Confusing or inappropriate part-time prohibition message.
- Excessively long red signal phase.
- The ease of making a right turn, particularly in cases of a narrow right-turn lane, sharp curb radius, etc.
- The operations of the intersection during all signal phases, including violations of the NO TURN ON RED sign and pedestrian-vehicle conflicts during the red and green signal phases.

5. Analyze the data and information for each site. The analyses should be used to answer the questions on the "Site Deficiency Form", shown in figure 7 for RTOR-allowed sites and figure 8 for RTOR-prohibited sites. For those specific problems which are identified, a "Yes" is checked in the figure, for use in countermeasure selection.

Step 3 - Select Countermeasures

Based on the determination of site deficiencies in Step 2, candidate countermeasures should be selected to minimize the RTOR-related problem. A summary of such countermeasures is given in table 4 for specific problems at RTOR-allowed sites and in table 5 for RTOR-prohibited sites. For example, if a site has a problem with high violation of the NO TURN ON RED

SITE DEFICIENCY FORM:
RTOR-ALLOWED SITES

Intersection_____

Approach_____ Date_____

	YES	NO
1. Does unused or confusing signal timing exist? If yes, explain._____	___	___
2. Is there poor sight distance on the approach? If yes, what is the problem? _____	___	___
3. Is there a problem with RTOR vehicles failing to make a full stop before turning right on red? If yes, please discuss._____	___	___
4. Are there many violations of the NO TURN ON RED sign? If so, how many? _____	___	___
5. Is there a high rate of NO-STOP violations? If so, what percent? _____	___	___
6. Are there frequent conflicts with cross-street traffic? If so, how many per hour? _____	___	___

Figure 7. Site deficiency form - RTOR-allowed sites.

SITE DEFICIENCY FORM: (continued)
RTOR-ALLOWED SITES

	YES	NO
7. Are there conflicts with pedestrians in the near crosswalk? If so, how many per hour? _____	___	___
8. Are there conflicts with pedestrians in the far crosswalks? If so, how many per hour? _____	___	___
9. Are any of the six MUTCD Warrants met for NO TURN ON RED signs? If so, which one(s)? _____	___	___
10. Would a part-time prohibition be justified?	___	___
11. Are pedestrian violations (of the DON'T WALK) creating a problem for RTOR vehicles? If so, what is the number and percent of pedestrians in the peak hour that are violating the signal? _____	___	___

12. Mention any other site deficiency which is observed which could affect safety or operations. _____

Figure 7. Site deficiency form - RTOR-allowed sites (continued).

SITE DEFICIENCY FORM:
RTOR-PROHIBITED SITES

Intersection_____

Approach_____ Date_____

	YES	NO
1. Are NO TURN ON RED signs hidden from view or difficult to read from the driver's perspective? If yes, please explain. _____ _____	___	___
2. Is the NO TURN ON RED sign placed near the traffic signal? If no, where is it located, and why? _____ _____	___	___
3. Are signal cycles too long or inappropriately set? If so, how could the signal timing be improved? _____ _____	___	___
4. Are problems occurring with pedestrians during the green phase? If so, explain the apparent cause._____ _____ _____	___	___
5. Is there a problem with vehicles violating the NTOR sign? If so, what is the percent of vehicle violations during the peak and off-peak periods? Peak _____% Off-Peak _____%	___	___

Figure 8. Site deficiency form - RTOR-prohibited sites.

SITE DEFICIENCY FORM: (continued)
RTOR-PROHIBITED SITES

	YES	NO
6. Are conflicts resulting from RTOR violations? If yes, does it involve cross-street traffic or pedestrians?___	___	___
7. Is the RTOR prohibition a full time prohibition? (i.e., 24 hours per day, 365 days/year) If there is a part-time prohibition, for what period is RTOR prohibited?_____	___	___
8. If a full-time prohibition currently exists, would a part-time prohibition be more appropriate? If so, for what periods?_____	___	___

Figure 8. Site deficiency form - RTOR-prohibited sites (continued).

Table 4. Summary of candidate countermeasures at RTOR-allowed sites.

Site Deficiency	Candidate Countermeasures
1. Unusual or confusing signal timing	1. Install NO TURN ON RED sign if warranted. 2. Retime traffic signal. 3. Install part-time RTOR prohibition sign or variable message NO TURN ON RED display. 4. Install RIGHT TURN ON RED AFTER STOP sign to encourage full stops. 5. Use special pedestrian signal display (i.e., WALK WITH CARE signal message during the WALK interval). 6. Install special pavement markings in crosswalk (i.e., LOOK FOR TURNING VEHICLES).
2. Poor sight distance	1. Prohibit RTOR if warranted. 2. Install offset or angled stop bars. 3. Relocate crosswalk further from intersection. 4. Install RTOR AFTER STOP sign to encourage full stop. 5. Remove roadside clutter.
3. RTOR vehicles fail to make a full stop or yield to pedestrians	1. Install RIGHT TURN ON RED AFTER STOP sign to encourage full stops 2. Install NO TURN ON RED sign if warranted. 3. Install part-time RTOR-prohibition sign or variable-message NO TURN ON RED display. 4. Install YIELD TO PEDESTRIAN sign. 5. Install PEDESTRIANS WATCH FOR TURNING VEHICLES sign. 6. Re-time traffic signal. 7. Remove unwarranted traffic signals. 8. Relocate crosswalk further from intersection. 9 Use special pavement marking in crosswalk (i.e., LOOK FOR TURNING VEHICLES). 10. Construct pedestrian overpass/underpass.

Table 5. Summary of candidate countermeasures at RTOR-prohibited sites.

Site Deficiency	Candidate Countermeasures
1. NO TURN ON RED signs located on far side or inconspicuous to motorists	1. Illuminate NO TURN ON RED sign. 2. Increase sign size to improve visibility. 3. Relocate signs to near signal placement. 4. Use double NTOR signs for redundancy. 5. Utilize 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. Confusing or inappropriate part-time RTOR prohibition	1. Prohibit RTOR only during the hours of heavy pedestrian travel. 2. Utilize full RTOR prohibition on the approach. 3. Utilize variable message NTOR sign. 4. NTOR illuminated signal to be activated only during periods when RTOR is prohibited.
3. Long cycle lengths resulting in excess waiting time for right-turn motorists	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. Right-Turn-on-Green problem results from high right turn volume	1. Allow RTOR during certain periods or full time. 2. Install separate right-turn lane. 3. Provide separate protected phase for right-turn traffic and pedestrian traffic.

(NTOR) sign, candidate countermeasures include relocating the sign to be more conspicuous to motorists (i.e., near signal placement), using a larger NTOR sign, using dual NTOR signs, considering whether RTOR prohibition is warranted or not, using police enforcement, etc.

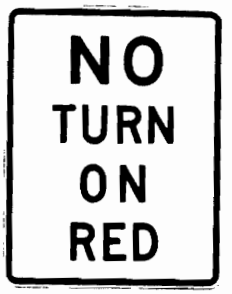
Since more than one of the site deficiencies may exist at a location, candidate countermeasures should be considered for groupings corresponding to all site problems. At sites where RTOR is currently allowed, the evidence of safety and/or operational problems should result in consideration of prohibiting RTOR. However, in such cases, a review should also be made of the problems which could result from Right-Turn-on-Green. At sites with full RTOR-prohibition and a high violation rate, an analysis should be conducted regarding whether RTOR prohibition is justified, or whether a part-time prohibition (or no prohibition) is preferred.

While the lists of possible countermeasures in tables 4 and 5 are intended to provide guidance in countermeasure selection, they should not be treated as the "only" countermeasures. The user should also consider any unique characteristics of the site, tempered with agency experience and local driver behavior. Ultimately, the user should use results of countermeasure evaluation (in Step 5) to determine which countermeasures are effective (and which are not) for various site conditions.

Step 4 - Install Countermeasures

After countermeasures are selected, they should be installed in a timely manner according to accepted practice. Some of the details to be remembered relative to implementation include:

- According to Section 2B-37 of the MUTCD, the standard NO TURN ON RED sign is a regulatory sign with standard dimensions of 24x30-in (60x75-cm) for the R10-11a (illustrated below) or 24x24-in (60x60-cm) for the R10-11b.



R10-11a
24"×30"

(60x75-cm)

- The NO TURN ON RED sign "should be erected near the appropriate signal head", according to page 2B-31 of the MUTCD.
- Part-time prohibitions are discussed in Section 2B-15 of the MUTCD, as follows:

> **When the movement restriction applies during certain periods only, the use of Turn Prohibition signs calls for special treatment. The following alternatives are listed in order of preference:**
>
> 1. **Variable message signs or internally illuminated signs that are lighted and made legible only during the restricted hours, particularly desirable at signalized intersections.**
> 2. **Permanently mounted signs incorporating a supplementary legend showing the hours during which the prohibition is applicable.**
> 3. **Portable signs off the roadway at each corner of the intersection where required, put in place under police supervision only when applicable and removed at other hours.**

- The use of offset stop bars was found to be effective at RTOR-allowed approaches in reducing RTOR conflicts with side street traffic and also in increasing the percent of vehicles making a full stop before turning right on red. The offset or angled stop bars should be considered at multi-lane RTOR-allowed approaches whenever a problem exists with limited sight distance or a high rate of NO-STOP violations by RTOR vehicles. Thermoplastic markings or durable paint is recommended, and offsets of 6 to 10 feet (1.8 to 3 m) are generally sufficient.

- The use of time restricted NTOR should be kept simple, if used. Complex time legends (i.e., NTOR - 7 AM - 9 AM, 3 PM - 6 PM, Monday- Friday, September-June) only confuse motorists, and such signs are commonly ignored by motorists. The NTOR WHEN PEDESTRIANS ARE PRESENT sign is one alternate message to be considered, particularly at sites with a low to moderate RTOR volume and intermittant pedestrian volumes.
- The use of electronic variable message signs are desirable, particularly at sites:[1]
  - Where pedestrian protection is critical during certain periods (such as school zones).
  - During a portion of the signal cycle where a separate opposing left-turn phase may conflict with an unsuspecting RTOR motorist.
  - Signs, signals, and markings related to RTOR must be properly maintained or replaced to insure their continued effectiveness.

Step 5 - Evaluate Countermeasure Effectiveness

The evaluation of the effectiveness of RTOR-related treatments is an extremely important aspect of any safety improvement program. In fact, detailed Users Manuals have been developed to provide information for conducting such evaluations.[7,8] The user should refer to those manuals for more information.

To briefly summarize the evaluation process as applied to RTOR, countermeasures should be evaluated in the following manner:

1. The short-term effect of the countermeasures should be evaluated using operational measures of effectiveness (MOE's) to determine whether the treatment is performing as intended. This is sometimes termed as a non-accident based (NAB) evaluation.
2. If similar types of countermeasures are installed at a large number of approaches (i.e., 50 or more), an accident-based evaluation of the program will provide information on their effect on related accident types.

Administrative evaluations should be conducted for countermeasures whenever possible. This involves an analysis of project costs, manpower expenditures, and material costs which were expended, as compared to the original estimates. Non-accident-based and accident based evaluations are discussed below.

A non-accident-based evaluation involves comparing appropriate operational MOE's before and after the countermeasure is installed. Operational measures that may have been collected in the before period include:

- Motorist violations of NTOR signs.
- Motorist failure to make a full stop before turning right on red (at approaches where RTOR is allowed).
- Conflicts between RTOR vehicles and cross-street traffic.
- Conflicts between RTOR vehicles and pedestrians.

Thus, if a countermeasure is installed to reduce one or more of these operational problems, then such measures could also be collected after countermeasure installation (during the same periods and days of the week) for evaluation purposes.

The MOE's must be carefully selected and must be appropriate to the selected countermeasure. For example, assume that a NO TURN ON RED sign is installed on an approach, the true effect of the sign may be to shift the right-turn problem from the red to the green phase. Thus, one appropriate MOE would be the number of right-turn conflicts with pedestrians (total of the red, amber, and green phases). If a larger NTOR sign or dual NTOR sign is installed to improve motorist compliance at an existing NTOR site, a suitable MOE might be the proportion of RTOR violations. In all cases, the MOE should be selected based on the objective of the countermeasure (i.e., What types of operational measures is this countermeasure installed to reduce?). A summary of selected MOE's is shown in table 6, as used in evaluating seven RTOR-related countermeasures in the study by Zegeer and Cynecki.

Table 6. Summary of the MOE's selected for analyzing countermeasures.

Countermeasure	No. of Test Sites	RTOR Violations	RTOR Ped. Conflicts	RTOR Ped. Conflicts + Interactions	Total (RTOR + RTOG) Ped. Conflicts	Total Ped. (RTOR + RTOG) Conflicts + Interactions	RTOR Vehicle Conflicts
1. Red Ball NO TURN ON RED Sign	6	●	●	●	●	●	●
2. Larger NO TURN ON RED Sign	5	●	●	●	●	●	●
3. NTOR WHEN PEDESTRIANS ARE PRESENT	4	●	●	●	●	●	
4. Red Ball NTOR Sign WHEN PEDESTRIANS ARE PRESENT	3	●	●	●	●	●	●
5. Offset Stop Bar	3		●	●	●	●	●
6. LOOK FOR TURNING VEHICLES Pavement Marking	8		●	●	●	●	
7. Variable Message NTOR/ Blank-Out Sign	3	●	●	●	●	●	●

● = Selected MOE's

After collecting the MOE's for the before and after periods, they should be compared using statistical tests, such as given below (with analysis questions):

- Chi-square (Are the frequencies for one group significantly different from that of another?).
- Z-test for proportions (Is the proportion of occurrences in one group significantly different from the proportion in a second group?).
- Paired t-test (Is the mean for a group of locations significantly different from the after mean for the same group of locations?).
- F-test (Is there a significant difference between the variance of two populations?).

A summary is given in figure 9 of the statistical test equations, as taken from the FHWA Accident Research Manual.[8]

The Z-test for proportions, for example, was used in a previous study for evaluating the seven RTOR-related countermeasures.[1] The population of RTOR vehicles involved in a conflict or violation was determined for the before and after periods at each site. An example of results of the evaluation of the red ball NTOR sign using the Z-test for proportions is given in table 7.[1]

Accident-based evaluations are possible only when an adequate sample of related accident types are available for statistical testing. Because RTOR-related accidents are generally rare at a given intersection, a project-by-project evaluation may not be possible in most cases. However, the grouping of numerous projects of a similar type into a "program" may allow for an accident-based evaluation. The use of control sites is essential in performing a reliable accident-based evaluation to account for external threats to validity. The need for control sites is not nearly as important with non-accident based evaluations, since the after data and the before data are usually collected within a few weeks or months. Methods of performing accident-based evaluations are described in detail in two FHWA Manuals.[7,8]

x^2 FOR POISSON FREQUENCIES

Analyses Question: Are the frequencies for one group significantly different from that of another?

Type of Data: Discrete (e.g., accident counts)

Underlying Assumptions: Data follow a Poisson process.

Statistic:

$$x^2 = \sum_{j=1}^{k} \frac{(N_{Aj} - \hat{N}_{Aj})^2}{N_{Aj}}$$

where

$$\hat{N}_{Aj} = \frac{t_{Aj}}{2} \left(\frac{N_{Bj}}{t_{Bj}} + \frac{N_{Aj}}{t_{Aj}} \right)$$

t_{Aj} = length of the j-th time period for the after (A) sample; likewise for t_{Bj}.

N_{Aj} = number of accidents in the j-th time period for the after (A) sample; likewise for N_{Bj}.

k = number of locations.

Interpretation: If $x^2 > \chi_c^2$ with k degrees of freedom, reject null hypothesis of no difference.

Modifications: None.

F-TEST

Analysis Question: Is there a significant difference between the variances of two populations?

Type of Data: Continuous

Underlying Assumptions:

1. Independent random samples.
2. Underlying distributions are normal.

Statistic:

$$F = \frac{S_A^2}{S_B^2}$$

where

$$S_A^2 = \sum_{i} \frac{(x_{Ai} - \bar{x}_A)^2}{N_A - 1}$$

S_B^2 likewise

Interpretation: If $F > F_c$ where d.f. = $((N_A-1), (N_B-1))$ then the variances are significantly different.

Modifications: None

Figure 9. Summary of statistical test equations. Source: Reference [8]

Z-TEST FOR PROPORTIONS

Analysis Question: Is the proportion of occurrences in one group significantly different from the proportion in a second group.

Type of Data: Continuous (proportions)

Underlying Assumptions:

1. Underlying distribution is binomial (observation is either success or failure -- no other level)
2. Observations are independent.
3. Large samples are collected in each group ($N > 30$).

Statistic:

$$z = \frac{p_1 - p_2}{\sqrt{p(1-p)\left(\frac{1}{N_1} + \frac{1}{N_2}\right)}}$$

where $p_1 = \frac{x_1}{N_1}$

$p_2 = \frac{x_2}{N_2}$

$p = \frac{x_1 + x_2}{N_1 + N_2} = \frac{N_1 p_1 + N_2 p_2}{N_1 + N_2}$

x_1 = number of occurrences in group 1 (e.g., serious injuries); likewise for x_2.

N_1 = number of possible occurrences or trials (e.g., number of drivers); likewise for N_2.

Interpretation: If $z > z_c$, the difference in proportions is statistically significant.

Modifications: If $N < 30$, refer to Ostle, 1969, p. 116.

Figure 9. Summary of statistical test equations (continued).

Source: Reference [8]

PAIRED T-TEST

Analysis Question: Is the before mean for a group of locations significantly different from the after mean for the same locations.

Type of Data: Continuous

Underlying Assumptions: Underlying distributions are approximately normal with means μ_B, μ_A, and variances σ_B^2, σ_A^2, respectively.

Statistic:

$$t = \frac{\bar{x}_B - \bar{x}_A}{s_D / \sqrt{N}}$$

where $\bar{x}_B$ = Before sample mean.

$\bar{x}_A$ = After sample mean.

and

$$s_D^2 = s_B^2 + s_A^2 - 2\left[\frac{1}{N-1} \sum_{i=1}^{N} (x_{Bi} - \bar{x}_B)(x_{Ai} - \bar{x}_A)\right]$$

N = number of locations.

Interpretation: If $t > t_c$, difference in means is statistically significant where degrees of freedom is equal to the number of locations - 1.

Modifications: None

Figure 9. Summary of statistical test equations (continued).

Source: Reference [8]

Table 7. Summary of results for the red ball (symbolic) NO TURN ON RED sign.

Measure of Effectiveness	Opportunity Measure	Detroit (4 Sites)		Washington, D.C. (2 Sites)		All Combined (6 Sites)	
		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 Ped. Conflicts	RTOR Volume	-	-	-	-	-	-
RTOR Ped. Conflicts + Interactions	RTOR Volume	-	-	-	-	-	-
Total (RTOR + RTOG) Ped. Conflicts	Right-Turn Volume	A	A	A	A	A	A
	Pedestrian Volume	NC	NC	A	A	A	A
Total (RTOR + RTOG) Ped. Conflicts + Interactions	Right-Turn Volume	A	A	A	A	A	A
	Pedestrian Volume	NC	NC	A	A	A	A
RTOR Vehicle Conflicts	RTOR Volume	-	-	-	-	-	-

Legend:
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.
- = Insufficient sample size.

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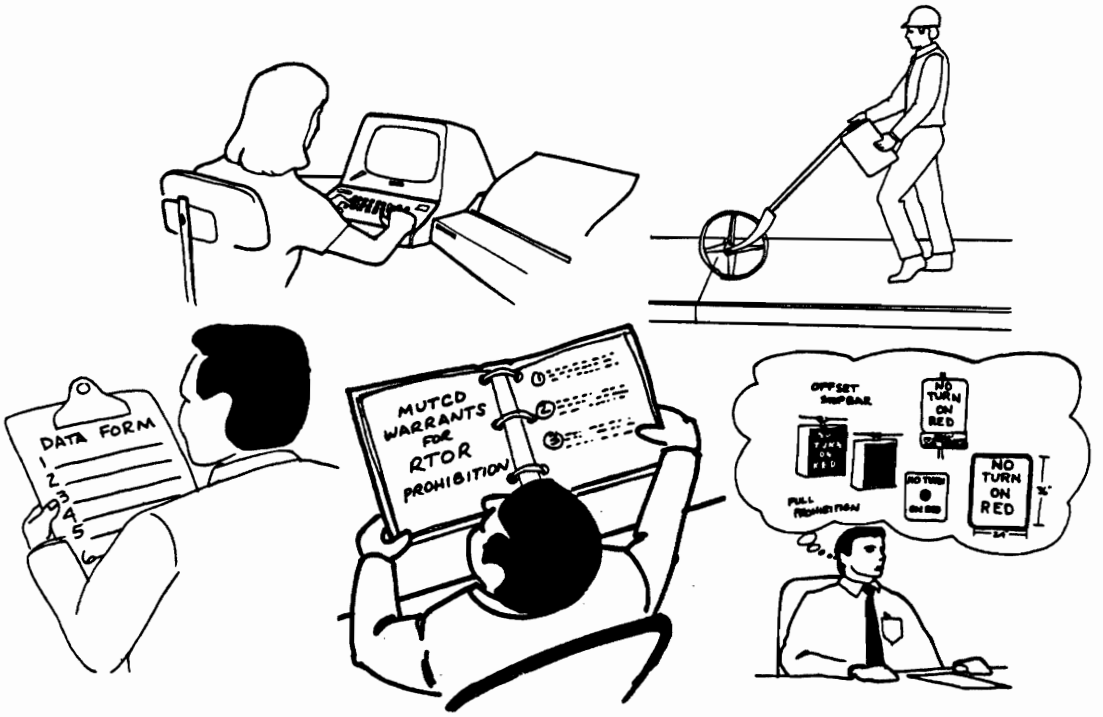
CHAPTER IV - REFERENCE LIBRARY FOR RTOR



The following is a list of references that were compiled and summarized related to Right-Turn-On-Red. Each reference is summarized according to its relevance to the following categories:

1) History of RTOR.
    a) Practices.
    b) Laws.
2) Current Use of RTOR.
3) Warrants.
4) Liability Issues.
5) Safety Impacts.
    a) Motor Vehicle Accidents.
    b) Pedestrian Accidents.

Each reference is then summarized according to the type of accident and/or operational studies performed (if any) by the reference author(s).

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7. Massachusetts Executive Office of Transportation and Construction, "Right-Turn-On-Red Safety Study For Massachusetts," prepared for the Governor's Energy Policy Office, April 1978.

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Summary of RTOR-related accident and operational studies.

Author & Title	Date	History of RTOR		Current Use	Warrants	Liability Issues	Safety Impacts	
		Practices	Laws				Motor Vehicle Accidents	Pedestrian Accidents
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3. Baumgartner, W.E., "... After STOP Compliance with RTOR After Stop"	1981	●		●				
4. Benke, R.J., and Ries, G.L., "RTOR Permissive Signing vs. Basic Law"	1973	●	●					
5. Biotechnology, Inc., "Model Pedestrian Safety Program - User's Manual"	1978							
6. Chamberlain, Gary, M., "Traffic Engineers Fight RTOR Proposal"	1972						●	
7. Chang, Man-Feng, et al., "Observations of Fuel Savings Due to Right-Turn-On-Red"	1977	●						
8. Clark, J.E., et al., "The Public Good Relative to RTOR in S. Carolina and Alabama"	1982	●					●	●
9. Cross, S., "Right-Turn-On-Red Signal"	1968	●			●		●	●
10. FHWA, Manual on Uniform Traffic Control Devices	1978				●			
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13. Glauz, William D., "Application of Traffic Control Analysis at Intersections"	1980							
14. Habib, Philip, "Pedestrian Safety: The Hazards of Left-Turning Vehicles"	1980							

Summary of RTOR-related accident and operational studies (continued).

Author & Title	Date	History of RTOR		Current Use	Warrants	Liability Issues	Safety Impacts	
		Practices	Laws				Motor Vehicle Accidents	Pedestrian Accidents
15. Hochstein, Sam, "Now is the Time For All Good Traffic Engineers..."	1981						●	●
16. Hooper, K.G., "ITE Technical Council Reacts to the Latest RTOR Controversy"	1981						●	●
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19. ITE RTOR Task Force - "Final Report"	1981							
20. ITE Committee 4A-17, "Guidelines for Prohibition of Turns on Red"	1982	●			●			
21. ITE Committee 3M(65), "Right-Turn-On-Red"	1968	●					●	●
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27. McGee, H.W., "Accident Experience With RTOR"	1977						●	●
28. McGee, H.W., "Guidelines for Proh. RTOR at Signalized Intersections"	1978				●			
29. McGee, H.W., et al., "Right-Turn-On-Red" Volumes I and II	1976	●	●	●	●	●	●	●

Summary of RTOR-related accident and operational studies (continued).

Author & Title	Date	History of RTOR		Current Use	Warrants	Liability Issues	Safety Impacts	
		Practices	Laws				Motor Vehicle Accidents	Pedestrian Accidents
30. McGee, H.W., "RTOR: Current Practices and State-of-the-Art"	1974	●	●	●	●		●	●
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33. Norman, M.R., "Institute Holds RTOR Forum"	1981							
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Summary of RTOR-related accident and operational studies (continued).

Author & Title	Date	History of RTOR		Current Use	Warrants	Liability Issues	Safety Impacts	
		Practices	Laws				Motor Vehicle Accidents	Pedestrian Accidents
44. Scott, P.M. III, "Economic Benefits of Reduced Delay Due To Selected Control Procedures"	1967						●	●
45. Senate Subcommittee - "Right-Turn-On-Red Signal"	1975							
46. VanGelder, William G., "Stop on Red Then Right Turn Permitted"	1959							
47. Wagner, F.A., "Energy Impacts of Urban Transportation Improvements"	1980			●				
48. Zador, P. et al., (IIHS), "Adoption of RTOR; Effects on Crashes at Signalized Intersections"	1980	●					●	●

Summary of RTOR-related accident and operational studies (continued).

Author	Motorist Compliance		Operational Impacts				Countermeasures		Counter-measure Costs	Economic Impacts	General
	RTOR Permitted	RTOR Prohibited	Vehicle Delay	Pedestrian Delay	Vehicle/Ped Conflicts	Other	Pedestrian	Other Treatments			
1. Atkins	●		●			●					●
2. Barnhart											●
3. Baumgartner	●							●			●
4. Benke	●	●	●								●
5. Biotechnology							●				
6. Chamberlain											
7. Chang			●			●					●
8. Clark			●			●				●	●
9. Cross	●		●		●						●
10. FHWA, MUTCD											
11. Galin			●		●	●					●
12. Galin											●
13. Glauz					●						
14. Habib					●		●				

Summary of RTOR-related accident and operational studies (continued).

Author	Motorist Compliance		Operational Impacts				Countermeasures		Counter-measure Costs	Economic Impacts	General
	RTOR Permitted	RTOR Prohibited	Vehicle Delay	Pedestrian Delay	Vehicle/Ped Conflicts	Other	Pedestrian	Other Treatments			
15. Hochstein											●
16. Hooper	●										●
17. Howard											
18. IIHS											●
19. ITE RTOR Task Force											●
20. ITE Committee 4A-17							●	●			●
21. ITE Committee 3M(65)			●								
22. Josey	●				●						●
23. Kearney											●
24. Mamlouk	●	●		●	●			●			●
25. Mass. DPW	●	●	●		●	●	●	●			●
26. May			●	●	●						●
27. McGee											
28. McGee											
29. McGee			●	●	●	●	●	●		●	●

Summary of RTOR-related accident and operational studies (continued).

Author	Motorist Compliance		Operational Impacts				Countermeasures		Counter-measure Costs	Economic Impacts	General
	RTOR Permitted	RTOR Prohibited	Vehicle Delay	Pedestrian Delay	Vehicle/Ped Conflicts	Other	Pedestrian	Other Treatments			
30. McGee		●	●	●							●
31. Minn. Dept. of Hwys.			●								
32. Nemeth											●
33. Norman											●
34. Nowak			●			●	●	●		●	●
35. Oklahoma City Dept. of Traffic Control											
36. Orne			●			●					●
37. Pagan											●
38. Parker	●	●	●		●	●	●	●	●	●	●
39. Parker	●	●	●		●	●	●	●		●	●
40. Preusser							●				●
41. Ray			●	●							●
42. Ray											
43. Robertson							●				

Summary of RTOR-related accident and operational studies (continued).

Author	Motorist Compliance		Operational Impacts				Countermeasures		Counter-measure Costs	Economic Impacts	General
	RTOR Permitted	RTOR Prohibited	Vehicle Delay	Pedestrian Delay	Vehicle/Ped Conflicts	Other	Pedestrian	Other Treatments			
44. Scott											
45. Senate Subcommittee											●
46. VanGelder			●								
47. Wagner			●			●		●		●	●
48. Zador											●

APPENDIX - SAMPLE SITE DATA FORMS

RTOR - SITE DATA FORM

INTERSECTION _____ AND _____ DATE _____

CITY/COUNTY _____ STATE _____

OBSERVER _____

AREA TYPE

Rural _____
Residential _____
Commercial _____
Industrial _____
CBD _____

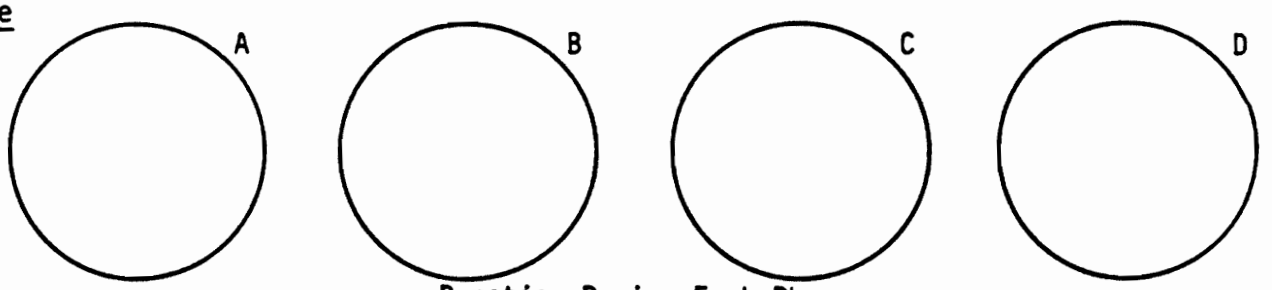
WEATHER _____ TEMPERATURE _____

PAVEMENT CONDITION _____

Approach	Sight Distance	Posted Speed	Offset Stop Bar	RTOR Prohibitions	RTOR Sign Mounting

Signal Timing

Phase



Duration During Each Phase

Interval	A	B	C	D	E
Red					
Green					
Amber					
Walk					
Clearance					
DONT WALK					

Cycle Length _____

RTOR ACCIDENT SUMMARY FORM

City: _____ Intersection: _____

Time Period _____ to _____ Approach: _____

Accident Type	Accident Severity					Total
		No. Injury Accidents (No. of Injuries)				
	PDO	A	B	C	Fatal	
RTOR with Cross-Traffic						
RTOR with Pedestrians						
RTOR Indirect Involvement						
RTOG with Pedestrians						
Other with Pedestrian						
Rear-end						
Right-Angle						
Other						
Total						

RTOR CONFLICTS AND VOLUME DATA FORM.

City: _____ Observer: _____

Intersection: _____ Approach: _____

Weather: _____ Date: _____

Ped. Conflict Types
VH = Vehicle Hesitation
VS = Vehicle Swerve
PH = Pedestrian Hesitation
PR = Pedestrian Run
I = Interaction

Period	Time		Right-Turn Volume		Right-Turn-on-Red				Pedestrian Volume	
							Ped. Conflict			
	From	To	RTOR	RTOG	No Conflict	Conflict with Traffic	Near Crosswalk	Far Crosswalk	Near Crosswalk	Far Crosswalk
1										
2										
3										
4										
5										
6										
Total										

RTOR AND STOP SIGN STOPPING CHARACTERISTICS DATA FORM

CITY: _____ OBSERVER: _____

LOCATION: _____ WEATHER: _____

DATE: _____

Check One ____ Traffic Signal ____ Stop Sign

Period	Time		Approach	Right Turn On Green (Signalized Locations Only)	Right-Turn-On-Red				Pedestrian Volume		Opposing Traffic
	From	To			No Stop	Rolling Stop	Full Stop		Near Side	Far Side	
							Voluntary	Forced			
1											
2											
3											
4											
5											
6											
TOTAL											

SITE DEFICIENCY FORM:
RTOR-ALLOWED SITES

Intersection_____

Approach_____ Date_____

	YES	NO
1. Does unused or confusing signal timing exist? If yes, explain._____	___	___
2. Is there poor sight distance on the approach? If yes, what is the problem? _____	___	___
3. Is there a problem with RTOR vehicles failing to make a full stop before turning right on red? If yes, please discuss._____	___	___
4. Are there many violations of the NO TURN ON RED sign? If so, how many? _____	___	___
5. Is there a high rate of NO-STOP violations? If so, what percent? _____	___	___
6. Are there frequent conflicts with cross-street traffic? If so, how many per hour? _____	___	___

SITE DEFICIENCY FORM: (continued)
RTOR-ALLOWED SITES

	YES	NO
7. Are there conflicts with pedestrians in the near crosswalk? If so, how many per hour? _____	___	___
8. Are there conflicts with pedestrians in the far crosswalks? If so, how many per hour? _____	___	___
9. Are any of the six MUTCD Warrants met for NO TURN ON RED signs? If so, which one(s)? _____	___	___
10. Would a part-time prohibition be justified?	___	___
11. Are pedestrian violations (of the DON'T WALK) creating a problem for RTOR vehicles? If so, what is the number and percent of pedestrians in the peak hour that are violating the signal? _____	___	___

12. Mention any other site deficiency which is observed which could affect safety or operations. _____

SITE DEFICIENCY FORM:
RTOR-PROHIBITED SITES

Intersection _____

Approach _____ Date _____

	YES	NO
1. Are NO TURN ON RED signs hidden from view or difficult to read from the driver's perspective? If yes, please explain. _____ _____	___	___
2. Is the NO TURN ON RED sign placed near the traffic signal? If no, where is it located, and why? _____ _____	___	___
3. Are signal cycles too long or inappropriately set? If so, how could the signal timing be improved? _____ _____	___	___
4. Are problems occurring with pedestrians during the green phase? If so, explain the apparent cause._____ _____ _____	___	___
5. Is there a problem with vehicles violating the NTOR sign? If so, what is the percent of vehicle violations during the peak and off-peak periods? Peak _____% Off-Peak _____%	___	___

SITE DEFICIENCY FORM: (Continued)
RTOR-PROHIBITED SITES

	YES	NO
6. Are conflicts resulting from RTOR violations? If yes, does it involve cross-street traffic or pedestrians?___	___	___
7. Is the RTOR prohibition a full time prohibition? (i.e., 24 hours per day, 365 days/year) If there is a part-time prohibition, for what period is RTOR prohibited?_____	___	___
8. If a full-time prohibition currently exists, would a part-time prohibition be more appropriate? If so, for what periods?_____	___	___