

RIGHT-TURN-ON-RED IN INDIANA

MICHEL MAMLOUK, Graduate Instructor in Research
RONALD L. MAY, Graduate Instructor in Research
HAROLD L. MICHAEL, Associate Director
Joint Highway Research Project
Purdue University

RIGHT-TURN-ON-RED HISTORY

The controversial Right-Turn-On-Red (RTOR) at signalized intersections began in 1937 when some authorities in California became convinced that motorists making right turns were wasting too much time waiting for the green traffic signal. These authorities first experimented with permitting motorists to make a right turn while facing a red signal only when a sign was in place allowing such action (permission by exception). In 1947 the state of California passed legislation permitting the RTOR movement at all signalized intersection approaches unless a sign was in place prohibiting the movement (permission by rule). In both cases the driver was required to stop first and yield to pedestrians and other vehicles properly approaching the intersection.

Since that time, permitting motorists to make a RTOR has spread gradually throughout the country because of its reduction of traffic delays and fuel consumption. Table 1 shows the use of RTOR in several recent years. Due to the different practices in the different states, the result has been much confusion for the driver as he travelled from one state to another.

TABLE 1 STATES THAT USED RTOR

	1972	1974	Mid-1976
Permission by rule	13	22	36
Permission by exception	19	20	14
Total exclusion	18	8	0*

*The District of Columbia, however, did not permit RTOR in any form.

As drivers have increased their area of travel over the years, the need for uniform standards for traffic control devices has increased. Since publication of the first edition of the *Manual on Uniform Traffic Control Devices* (MUTCD) in 1927, considerable evolution of this standard manual has occurred.

In the 1954 MUTCD, the RTOR maneuver was highly discouraged because of fear it weakened the clear meaning of the red indication. Since there was little established evidence to counter the premise that RTOR might add hazard when permitted, the 1961 MUTCD still stated that permitting the maneuver was not recommended. The 1971 MUTCD, however, permitted the RTOR but only when a sign was in place permitting the turn. The driver was required to come to a complete stop before making his turn.

In August 1972 the National Highway Traffic Safety Administration (NHTSA) proposed in the Federal Register that all states would be required to enact legislation to permit the RTOR maneuver at all locations unless a sign was in place prohibiting the turn.⁵ At that time many traffic authorities objected to this method of revising the uniform control device standards. Finally, permitting the RTOR maneuver by rule was incorporated in July 1975 into the Uniform Vehicle Code, another national standard developed by the National Committee on Uniform Traffic Laws and Ordinances to establish consistent traffic laws throughout the country.

In Indiana, RTOR has been permitted by sign for many years but few intersection approaches had been so signed. In 1973 the Indiana Legislature mandated RTOR by rule effective July 1, 1974.

PAST RESEARCH FINDINGS

The matter of RTOR has been examined in many studies. Some of these studies have been theoretical while others were reports of actual field surveys.

Accident Studies

Almost all pertinent studies have come to the conclusion that RTOR maneuver accidents are a very small portion of the total accident experience. Some reports even indicated that the RTOR maneuver may be safer than right turn on green. It also appears that pedestrians may be safer with the RTOR maneuver than with right turn on green. Only one study by May reported any increased accident experience with the maneuver.⁷

Vehicle Delay and Travel Time

It was found in several studies that delay to right turning vehicles was reduced without increasing the delay for other vehicles at the intersection. Also, it was found that travel time over a prescribed course which included a right turn was reduced. This delay reduction varied from 20.1 seconds to 9.7 seconds saved per right turning vehicle in one of the studies. In another study it was found that the average amount of time saved per vehicle appeared to be directly proportional to the length of the red phase of the signal cycle in the case of two-phase, fixed time signals. It was also determined that the presence or number of pedestrians had no real effect on the amount of time saved with use of the RTOR maneuver.

Gap Availability

Most of the literature dealing with gaps concerned itself with the size of gap which would be accepted for a RTOR maneuver. The size of reported acceptable gaps for right turning vehicles ranged from a minimum of 4.25 seconds to a median of 7.36 seconds. It was also found that adequate acceptable gaps generally exist in pedestrian traffic for right turning vehicles.

Capacity and Level of Service

A model was developed by one study to evaluate the RTOR volumes resulting from the maneuver.¹⁸ When the equation was tested in the field, it was found that it provided a reasonable estimate of the maximum limit of RTOR maneuver volumes. It was found that the use of the RTOR maneuver did not increase the total capacity of an intersection, but that it could improve the level of service of an approach if the cross-street was not operating at capacity.

Driver Compliance

A study by the Minnesota Department of Highways compared driver performance under permission by signing and permission by rule in the state of Minnesota.⁸ In general, the study found little difference in RTOR rejection for the permission by sign and permission by rule cases. There did appear to be more violations (illegal RTOR) with the rule case than for the sign case.

Warrants

A variety of warrants for use of the RTOR maneuver have been used throughout the country. Almost all of these warrants were arbitrary, and the application of them has been very subjective.

One warrant which generally has been long accepted is that the RTOR maneuver should not be permitted where sight distance is in-

adequate. Inherent with sight distance and the RTOR maneuver is the fact that an acceptable gap for the maneuver must be visible if the movement is to be made safely. Work performed on gap acceptance by Solberg and Oppenlander resulted in the conclusion that the median acceptable gap for a right turning vehicle is approximately 7.36 seconds.¹⁶

FIRST STUDY AT PURDUE

Study Design

During 1973 and 1974 a research project on RTOR was performed in the cities of Lafayette and Indianapolis in Indiana. This project was directed toward developing warrants for prohibiting RTOR as the new Indiana law required an engineering study at each intersection to determine if RTOR should be prohibited under the RTOR by rule.

For the Lafayette study, the research objective was to determine changes in levels of various intersection characteristics. A before and after technique was used for measuring these changes. The before study examined the approach legs of several intersections considered for implementation of the maneuver. A RTOR sign was then installed at each location. After a one-month period each approach was again examined to measure any changes which had occurred.

The variables that were measured in this study were:

1. Number of phases per signal cycle.
2. Length of red phase.
3. Length of cycle.
4. Nature of cross traffic flow upstream.
5. Speed of cross traffic upstream.
6. Speed of approach traffic.
7. Volume of cross traffic upstream.
8. Volume of approach traffic.
9. Volume of pedestrians crossing approach street.
10. Number of through lanes of cross traffic upstream.
11. Percent of turning movements of cross traffic upstream.
12. Number of approach lanes.
13. Availability of right turn only lane.
14. Percent of right turn approach volume.
15. Width of approach street.
16. Number of cross traffic lanes upstream.
17. Volume of left turn on opposite approach on separate phase.
18. Sight distance.
19. Pedestrian delay.

20. Vehicle delay.
21. Accident potential.

All the measurements were taken on an hourly basis. Each intersection was studied for four hours including both peak and nonpeak periods during both the before and after studies. For the study, twelve approaches at four intersections were selected. The dependent variables consisted of pedestrian delay, delay savings to vehicles, accident potential, and volume changes.

A moving car technique was used to measure vehicle delay savings. A vehicle was driven through the intersection making a right turn from the study approach. Before entering the intersection, a stop watch was started at a predetermined reference point. After traveling through the intersection, the stop watch was stopped at a second predetermined reference point. These reference points were selected in an arbitrary manner, but attempts were made to select points located where the vehicle had not started to slow down as it approached the intersection or was not accelerating as it came away from the intersection. In the before study, all turns were made against a green signal. In the after study, the turns were made as soon as they could be made safely. Ten random runs were made each hour in both the before and after studies. The ten runs were averaged and the difference between the before and after averages was taken to be the average delay reduction resulting from the RTOR maneuver.

A critical incident method was used to measure accident potential. The observer simply counted and recorded all defensive maneuvers by drivers, such as a swerve or severe braking, which he felt resulted from the driver attempting to avoid an accident. The count of these critical maneuvers, or accident potential, was recorded for both the before and after studies. The intent was to use the difference in these numbers, with the appropriate traffic volumes taken into consideration, as the relative change in accident expectation resulting from the RTOR maneuver.

An attempt was also made to measure driver irritation resulting from the RTOR maneuver. It was felt that some drivers would display irritation when they were not able to make a right turn, because the vehicle in front of them was in their way. This measurement was recorded as the number of occurrences of any display of irritation such as drivers sounding their horns.

As a measure of driver acceptance, the number of situations where a vehicle making a right-turn had the opportunity to make it on red was recorded. Also, the number of drivers actually making the RTOR

maneuver was recorded. These counts permitted calculation of the percent of drivers who made a RTOR maneuver when given the opportunity.

Another study of RTOR vehicle effects was made at intersections in Indianapolis, Indiana. In late 1968 the City of Indianapolis installed signs permitting the RTOR maneuver at a large variety of intersections under their jurisdiction. Since the maneuver had been permitted there for approximately five years and the motoring public had a good opportunity to become accustomed to it, a number of Indianapolis intersections were evaluated.

Thirty-six intersection approaches were examined. Some of the intersections were near the CBD while others were in outlying areas. At each of the selected approaches, a four-hour study was made of pedestrian delay, accident potential, RTOR maneuver opportunities and use, and driver irritation. The data collected as measures of each of these factors were the same as for the before and after study in Lafayette except for pedestrian delay and accident potential. Rather than using the change in pedestrian delay occurrences by type, it became necessary (because of no before study) to simply use the number of pedestrian delay occurrences by type resulting from an RTOR maneuver. Rather than using the change in accident potential occurrences, it likewise became necessary to use the number of accident potential occurrences resulting from an RTOR maneuver.

It was further decided that a new dependent variable should be considered in the study, the number of gaps in the cross traffic, as they could be an important consideration for the RTOR maneuver. The number of gaps was measured by observation at each site. An adequate gap was recorded each time a gap large enough for one vehicle to make a right turn was observed. If the gap was large enough for more than one vehicle to turn, the number of vehicles which could have turned into the gap in the cross traffic was recorded.

The study also analyzed the available accident records from 1967 through 1970 for each of the selected RTOR maneuver intersections. A before and after study was performed to compare accident experiences before RTOR sign installation (1967-68) and after its installation (1969-70).

Accident Analysis

In the Lafayette study the accident data were too small to draw an absolute conclusion. In the Indianapolis study the accident information at RTOR maneuver intersections was broken into the categories of personal injury, property damage, and pedestrians. A before and

after study was performed to determine the effect of the RTOR maneuver on accidents.

In summary, it was concluded that the installation of RTOR maneuver signs had very little effect on accident experience at RTOR maneuver intersections. For personal injury accidents, the number of personal injuries increased after the signs were installed, but the increase was not significant at an alpha level of .05. In a similar manner, the number of property damage accidents decreased, but it also was not a significant difference. The total number of accidents, however, significantly decreased after the signs were installed.

RTOR Usage

During both the Lafayette and Indianapolis studies, the number of opportunities to perform a RTOR maneuver and the number of times these opportunities were utilized were recorded. These data were then used to compute the percent of the opportunities which were used. An opportunity to perform a RTOR maneuver was considered to exist when the first vehicle in the right curb lane desired to turn right while facing a red traffic signal and an appropriate gap was available. It was not considered to be a RTOR maneuver opportunity unless the vehicle eventually turned right, either on the green or red signal indication. The number of opportunities utilized were the opportunities when a vehicle performed the right turn before the signal changed to green.

The number of RTOR maneuver opportunities ranged from a low of no opportunities to a high of 174 opportunities per hour. The average number of opportunities was 16 per hour. The number of RTOR maneuvers performed ranged from a low of no maneuvers to a high of 173 maneuvers per hour. The average number of maneuvers was eight maneuvers per hour. The percentage of the RTOR maneuver opportunities which were utilized ranged from a low of zero percent to a high of 100 percent. The average percent utilized was 54.

Intersections approaches with cross traffic speed less than 35 miles per hour were found to have a significantly higher percentage of use of RTOR maneuver opportunities. Similarly intersection approaches with cycle lengths less than 70 seconds, with only one lane on the cross street, or with sight distance greater than 285 feet had significantly greater percentage of use of the RTOR maneuver opportunities.

Delay Reduction

A portion of the Lafayette study was designed to examine the reduction in vehicle delay to right turning vehicles at signalized intersections resulting from the RTOR maneuver. An average travel time

for vehicles making right turns at each study approach was determined for both the before and after studies. The delay reduction was taken to be the difference between the average travel time before and the average travel time after.

The reduced delay for the 12 approaches at the four intersections used in the Lafayette study ranged in value from a low of minus .20 seconds (an increase in delay of .20 seconds), to a high of 15.23 seconds. Ten intersection approaches out of 12 had significant delay reduction in the after period.

Pedestrian Delay

Very few occurrences of pedestrian delays were observed. A total of five pedestrians were forced to wait on the curb by a vehicle turning right on a green signal. One other pedestrian was forced to wait in the middle of the street by a vehicle turning right on a green signal. No pedestrian delays were observed during either the Lafayette study or the Indianapolis study resulting from a RTOR maneuver.

Pedestrian volumes in the study ranged from zero to approximately 130 pedestrians per hour with the majority of the samples having approximately 70 or less pedestrians per hour. It appeared that the RTOR maneuver had no adverse effects on pedestrian travel for the pedestrian volumes observed.

Driver Irritation

In both the Lafayette and Indianapolis studies, driver irritation incidents were recorded. These irritation occurrences were any occurrence which seemed to indicate that a driver desired the vehicle in front of him to perform the RTOR maneuver. In the study, as expected, the only form of driver irritation observed was a driver sounding his horn.

In the Lafayette study, only eight incidents of driver irritation were noted, and only seven occurrences were noted in the Indianapolis study. These intersections had very few common characteristics, and it appears that these occurrences were very random in nature.

SECOND STUDY AT PURDUE

Study Design

During 1975 and 1976, after RTOR had been in operation in Indiana by rule for one year, another study was performed in 18 cities. The study was to determine how RTOR was being used in Indiana by traffic officials and by motorists and how it affected accidents and traffic flow.

In the study, field observations were performed at 150 signalized intersection approaches where RTOR was permitted. The characteristics of each approach varied widely from one location to another. Several variables were measured in order to determine their effect on the performance of the RTOR maneuver. The different variables that were measured at each approach were as follows:

1. Number of vehicles which did not have the chance to turn on red either because of the high approach traffic volume or because of the high cross traffic volume.
2. Number of vehicles which refused to turn on red when they had the chance to do so.
3. Number of vehicles which arrived on green.
4. Number of vehicles which turned on red and came to a full stop or very low speed before turning.
5. Number of vehicles which turned on red and did not stop (or slow to very slow speed) before turning.
6. Total traffic volume on the studied approach (including right turning vehicles).
7. Total traffic volume approaching from the left (cross traffic).
8. Total cycle length.
9. Length of red phase.
10. Number of conflicts between RTOR vehicles and cross traffic.

The traffic conflict technique developed by General Motors Corporation was used to measure traffic accident potential of RTOR vehicles.¹² Previous use of this technique has shown it to be a potentially valuable tool for the evaluation of intersection operation. It provides significant data in a short testing period. Moreover, studies have shown that conflicts and accidents are associated.^{1, 10}

For a meaningful evaluation of the RTOR maneuver it was believed that the information which could be obtained from the traffic conflict technique would be more reliable than that available from accident history. Accident data may be inadequate, distorted, incorrect, or incomplete, while traffic conflict studies use objective criteria to obtain significant quantities of data in short observation periods.

Observation of conflicts was conducted during the same times as observation for other data. Conflicts were observed from a vehicle parked on the side of the roadway about 100 to 300 feet prior to the intersection. (See Figures 1 and 2.) The vehicle faced the direction of traffic movement and did not interfere with normal movements.

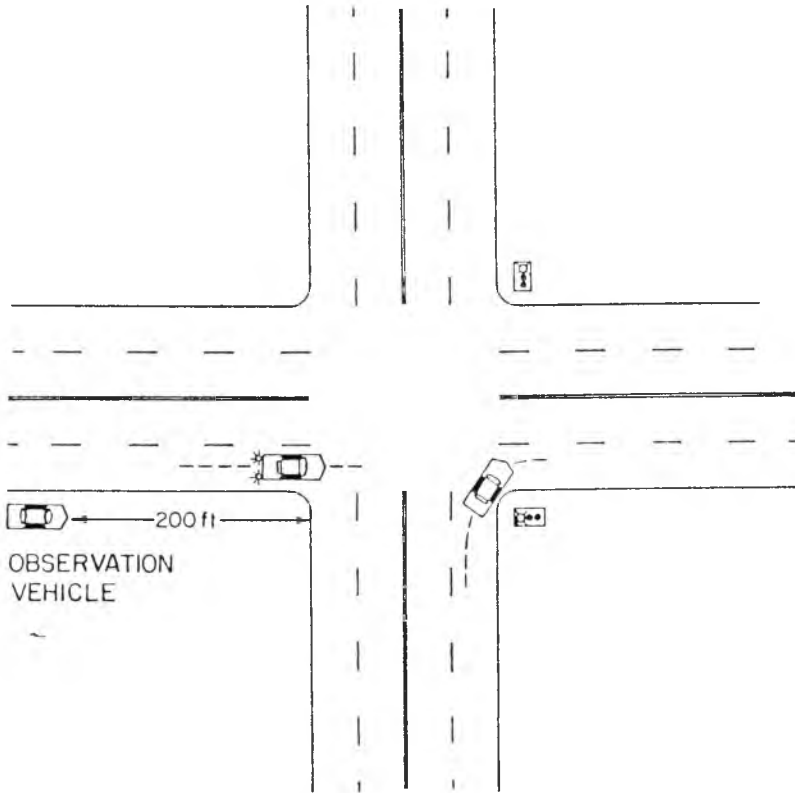


Figure 1. Right-Turn-on-Red Conflict (Braking)

Observations were conducted on weekdays with data collected at both off-peak and peak hours. Off-peak hours were considered from 9 to 11 a.m. while peak hours were considered from 4 to 6 p.m. Results were recorded after each observation hour for both off-peak and peak periods.

Physical characteristics of the studied intersections that were considered were:

1. Number of approach lanes.
2. Number of lanes of cross traffic upstream.
3. Availability of exclusive right turn lane.
4. Type of signal (progressive or nonprogressive).
5. City size. Cities of population more than 25,000 were considered to be large while cities of less than 25,000 were considered to be small.

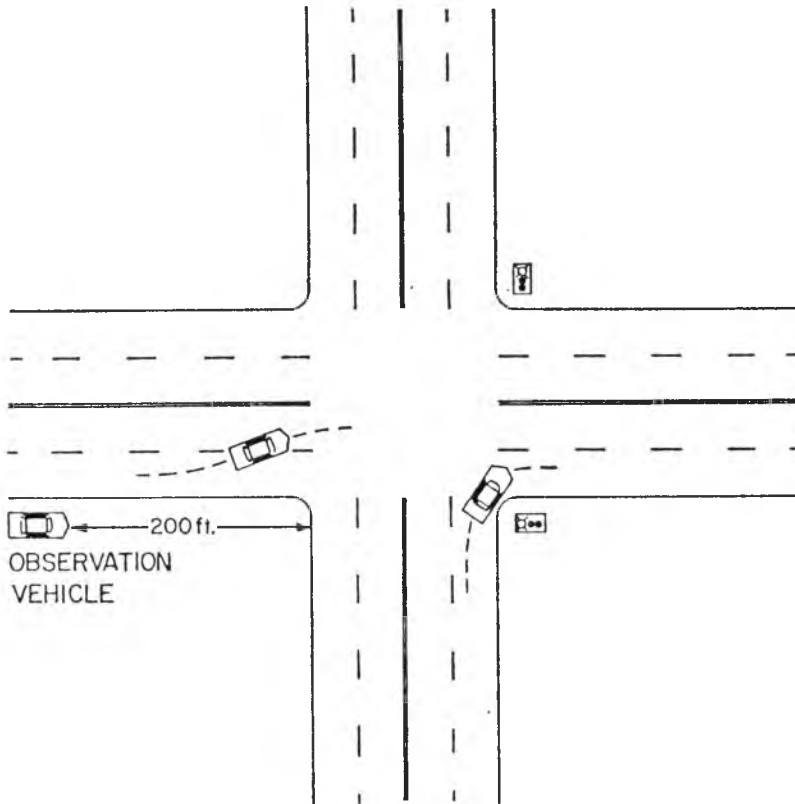


Figure 2. Right-Turn-on-Red Conflict (Lane Change)

Attempts were made to observe the nature of conflict between RTOR vehicles and pedestrians. Driver irritation was also observed in the same way as in the first study.

Left turn on red from a one-way street to another one-way street was also studied in a similar way as RTOR. Eight signalized intersection approaches were observed.

This second study also determined how drivers complied with NO TURN ON RED signs. Field studies were performed on a random sample of 38 signalized intersection approaches in 12 cities in Indiana where RTOR or LTOR was prohibited.

Right-Turn-on-Red Analysis

From the field observation data it was found that right turning vehicles averaged 19.0 percent of the total approach traffic volume. Total right turning vehicles were found to operate as shown below :

Arrived on red:	
RTOR vehicles	= 19.5%
Vehicles that refused to turn on red	= 10.1%
Vehicles that did not have the chance to turn on red	= 18.8%
Arrived on green	= 51.6%

As calculated from the above data the percent of vehicles using RTOR averaged only 3.7 percent of total approach traffic volume.

Analysis of variance tests were performed in order to determine the significant factors affecting the performance of the RTOR maneuver. Important factors that proved to be significant at a five percent level of significance were:

1. City size.
2. Number of approach lanes.
3. Availability of a right turn lane.
4. Approach traffic volume.
5. Cross traffic volume.
6. Percent of red signal time.

Averages of turning vehicles were calculated for the significant factors noted above as follows with all values as percent of total right turn vehicles:

	% RTOR	% Refused to Turn on Red
Small Cities	15.6	15.5
Large Cities	21.3	6.7
		% Refused to Turn on Red
One-lane Approach		11.2
Multilane Approach		6.4
	% RTOR	% No Chance to Turn on Red
Available right turn lane	26.3	11.2
No right turn lane	19.3	22.0

The type of signal also was important. The average percents of RTOR vehicles classified according to signal type were as follows:

	% RTOR
Progressive Signal	11.3
Nonprogressive Signal	21.2

It was also concluded that the percent of RTOR vehicles increased with a decrease of approach traffic volume and with a decrease of cross

traffic volume. Percent of RTOR vehicles increased also with an increase in the percent of red signal time. Percent of vehicles that refused to make a RTOR increased significantly with a decrease of the approach traffic volume. It was also found that percent of vehicles that did not have the chance to make the RTOR maneuver increased significantly with an increase of the approach traffic volume and with an increase of the cross traffic volume.

During 600 hours of observation, 56 RTOR vehicles did not stop or slow down to a low speed before turning. They represented 0.85 percent of the total RTOR vehicles.

Traffic Conflicts

During the 600 observation hours, 40 conflicts between RTOR vehicles and the cross traffic were observed. The number of conflicts did not exceed one or two per hour in any case while there were no conflicts at all in most cases. None of the observed conflicts were serious in nature.

The number of conflicts was observed to be higher when the traffic volume in the cross direction was high and fast. Also, it was observed that the number of conflicts was higher when the sight distance was not adequate to make the RTOR movement. It was also observed that the number of conflicts in large cities was higher than in small cities.

In summary, the RTOR movement did not cause a significant increase in the accident potential of the intersection. Although not quantitatively evaluated, RTOR might actually decrease certain types of traffic conflicts by clearing the intersection and expediting traffic movement.

Pedestrians

During the data collection periods, RTOR vehicles did not cause any new problems to pedestrians at the studied intersections. In almost every case motorists yielded the right of way to the pedestrians before turning. No unusual pedestrian delays were observed during the study periods resulting from a RTOR maneuver.

Although RTOR vehicles may be in conflict with some pedestrians crossing the approach, it should be noted that when vehicles turn on green they will be in conflict with a substantial percentage of the pedestrians in the cross street. As a result, pedestrian conflict with vehicles is not increased by the RTOR maneuver as compared to RTOG.

Driver Irritation

Six horns were recorded during the 600 observation hours as an indication of drivers desiring the vehicle in front of them to make a RTOR movement. On the other hand, the RTOR movement reduced driver irritation by preventing unnecessary delays. Many drivers probably prefer to turn on red rather than be compelled to wait for the green signal.

Left Turn on Red

From the field observations it was found that LTOR vehicles averaged only 1.3 percent of the total left turning vehicles. This was about 0.26 percent of the total approach traffic volume. This was much less than RTOR as the percent of drivers that refused the opportunity to make a LTOR was much higher than the percent of drivers that refused the opportunity to make a RTOR.

During the data collection periods, all drivers that made the LTOR maneuver came to a full stop or a rolling stop before turning. No traffic conflicts between LTOR vehicles and vehicles approaching from the right were recorded during the study period. Because of the very small LTOR, this movement had a very small probability of increasing the accident potential at signalized intersections. It was also observed that all vehicles which made a LTOR yielded to pedestrians before turning. No pedestrian delay of any kind was recorded due to the maneuver.

Turn-on-Red Prohibition

According to the field surveys at the approaches where the RTOR maneuver was prohibited, the number of violations ranged from zero to four per hour. Percent violations ranged from a low of zero percent to a high of ten percent of the total right turning vehicles. The average percent of violations was 1.4 percent of the total vehicles that made a right turn.

An attempt was made to determine the different factors that affected the number of violations. It was concluded that the number of violations increased when the approach traffic was heavy and the crossing traffic was light.

Also, it was observed that the number of violations was affected by the type of vehicle. The percent of motorcycles that turned on red where the maneuver was prohibited was more than for other vehicles. No RTOR violations were observed to be made by trucks at the studied locations.

A study was performed to determine the effect of NO TURN ON RED sign location on percent of violations. Most RTOR prohibition

signs were post mounted at the corners of the intersections, while the signs were overhead mounted. This situation could result in the sign being unnoticed. According to the data, however, no significant difference in percent of RTOR violations was observed between the locations where the sign was overhead mounted or post mounted.

Questionnaire on RTOR

One phase of the study included contact with traffic officials in the state of Indiana to evaluate their appraisal after one year of the quality of use of the RTOR maneuver in their city. In July 1975, a questionnaire was sent to the traffic engineers, traffic officers, or chiefs of police in all cities of Indiana. Replies were received from 74 cities distributed throughout the state. Traffic officials in some larger communities in Indiana were also interviewed to determine their utilization, including warrants used, of RTOR.

The data obtained from the questionnaire were tested for completeness and accuracy. The analysis of the answers indicated that the number of signalized intersection approaches at which the maneuver was prohibited ranged from zero to 83.1 percent of the total signalized approaches in the city, with an average of 12.0 percent. This means that the RTOR maneuver was permitted at 88 percent of the total signalized intersection approaches in the state.

According to the answers received from traffic officials, the reasons for RTOR prohibition and the average percent of the frequencies for each reason are shown in Table 2.

TABLE 2 REASONS FOR NOT PERMITTING RTOR
ON AN APPROACH

Reason	Average (%)
Inadequate sight distance	29
Separate conflicting turning phase	28
Heavy pedestrian crossing	14
More than four approaches into the intersection	8
Heavy cross street traffic	7
School crossing	7
Others	7

Twenty accidents attributed to RTOR movements during the one year of history were reported by the questionnaire respondents. Eighteen of these accidents occurred in large cities while only two accidents were

reported from small cities. All these accidents involved only minor property damages or minor injuries. No fatalities or serious injuries were reported in responses to the questionnaire. Most accidents were reported to have been caused by vehicles which did not come to a full stop before turning and proceeded into the intersection without yielding the right-of-way to the cross traffic. Only two of these accidents were classified as pedestrian accidents. They were reported in large cities during peak hours. These two accidents also occurred due to the drivers' failure to come to a complete stop before turning. It was noted that some of the reported RTOR accidents could be attributed to the poor design of the intersection or because of allowing RTOR at locations where it should be prohibited.

Most traffic officials in Indiana were in favor of allowing the RTOR as a basic rule because it tends to decrease the delay and improve the level of service at signalized intersections. The only problem reported was that some drivers do not come to a full stop before turning.

FINDINGS AND CONCLUSIONS

From the analysis of the data in these two research projects, certain observations and findings were made. These observations and findings are summarized below :

1. It was found that there was no increase in the total number of accidents after allowing the RTOR maneuver. Collision diagrams prepared from the accident data indicated that very few pedestrian accidents involved a RTOR maneuver.

It was observed that no pedestrians were placed in a more hazardous situation because of a RTOR maneuver during any of the data collection periods. Further, not a single instance of pedestrian delay caused by a RTOR maneuver vehicle was observed.

2. Delay reduction to right turning vehicles resulting from the RTOR maneuver was found. The amount of average delay reduction was found to vary from intersection approach to intersection approach, depending on length of red time on the approach, and varied from no reduction to as much as 15 seconds per right turning vehicle that used the RTOR maneuver.
3. Very little driver irritation was found with the RTOR maneuver, even in locations where it had been recently implemented. The only form witnessed was an occasional horn-blowing by a stopped following vehicle. Such notice to the driver ahead almost never resulted in his utilization of the RTOR maneuver.

4. Under the RTOR by rule the RTOR maneuver was made by an average of only 19.5 percent of the total right turning vehicles. This is 3.7 percent of the total approach volume.
5. Important factors that proved to have significant effects on the RTOR maneuver were:
 - a. City size; the percent of RTOR vehicles was 21.3 percent of the total right turning vehicles in large cities while it was 15.6 percent in small cities. Consequently, the percent of vehicles that refused the opportunity to turn on red in large cities was smaller than in small cities.
 - b. Number of approach lanes; it was found that percent of drivers refusing the opportunity to turn on red was higher on one-lane approaches than on multilane approaches.
 - c. An exclusive right turn lane; it was found that RTOR vehicles were 26.3 percent of the total right turning vehicles when a right turn lane was available, while this percent was 19.3 percent when there was not a right turn lane.
6. The percent of RTOR vehicles increased significantly with a decrease of the approach traffic volume and also with a decrease of the cross traffic volume.
7. The number of traffic conflicts between RTOR vehicles and the cross traffic was very small and did not cause any serious problems.
8. The LTOR maneuver was used by only 1.3 percent of the total left turning vehicles (0.26 percent of the total approach volume).
9. The percent of vehicles that made a RTOR at locations where the maneuver was prohibited was 1.4 percent of the total right turning vehicles.
10. Although a small number of vehicles did not come to a full stop (or slow to a very slow speed) before turning on red, they did not create major problems in the performance of the maneuver.
11. According to answers to a questionnaire that were received from the traffic officials in cities of Indiana, the RTOR maneuver was operating efficiently. The maneuver was allowed at 88 percent of all signalized intersection approaches in these cities. Most traffic officials are in favor of allowing the maneuver. Twenty RTOR accidents were reported in the questionnaire; however, they involved only minor property damages or minor injuries.

12. Problems that resulted from allowing the RTOR maneuver were:
- a. Some RTOR vehicles do not come to a full stop before turning.
 - b. Confusion occurs because all states do not have a uniform law concerning the maneuver.
 - c. Some drivers refuse to turn on red when they have the chance to do so.
13. On the basis of the findings of these studies and experience indicated in the literature warrants were suggested. These warrants were slightly revised by the Indiana State Highway Commission after further experience and are subdivided into three groups:
- A. TURNS ON RED *should* be prohibited for safety reasons where:
1. Minimum sight distance of cross street traffic as shown in the following table, is not available to the potential TURN ON RED motorist:

MINIMUM SIGHT DISTANCE

Speed of Cross Street Traffic	Sight Distance In Feet (Approx.)
20	220
25	270
30	330
35	380
40	430
45	490
50	540
55	600

Minimum sight distance should be measured from the driver's position with the vehicle at a point immediately prior to entry into the intersecting street. Where pedestrian signals are in place, the sight distance should be measured from the driver's position with the vehicle at the STOP LINE or, if none, the CROSSWALK location. The engineering investigation should include an estimate of the approach speed of the crossing traffic

since these speeds may be more or less than the posted speed.

2. A separate signal phase for a turning movement of which the TURN ON RED motorist may be unaware exists at the intersection, and which could conflict with a TURN ON RED movement; except when engineering investigations reveal that one of the following modifications to this warrant would be appropriate.
 - (a) The warrants and need for the LEFT TURN ARROW should be considered and if the arrow is not warranted or is of minimum need, the arrow should be removed, and the TURN ON RED permitted.
 - (b) When the left turn movement is fully warranted and made under a LEFT TURN ON ARROW ONLY situation, the conflicting RIGHT TURN ON RED maneuver should be prohibited; however, when two or more lanes are available to receive the turning vehicles, the TURN ON RED movement should be considered along with the volumes of the respective turns and the lane widths involved. A minimum width of 11 feet is normally considered to be adequate for a lane.
 - (c) Where only one exiting lane is available to receive the turning vehicles or where double lane left turn movements are permitted, the conflicting TURN ON RED maneuver should be prohibited; however, the movement may be permitted in special cases involving one-way streets and one-way interchange ramps where conflicts are minimal.
3. The intersection has more than four approaches. At such locations cross street traffic which conflicts with the TURN ON RED may not be quickly identified by the TURN ON RED motorist or the TURN ON RED motorist may be able to turn into more than one street, thus creating unexpected conflicts. However, TURN ON RED maneuvers may be allowed at multi-legged intersections when it is apparent that no unexpected conflicts would be involved as, for example, when the use of ONE-WAY streets would preclude traffic conflicts; where special channelization is in place;

or where signal phasing is of such nature that conflicts are minimal.

- B. TURNS ON RED *may* be prohibited because of little benefit from the maneuver at locations where:
1. There is a very short RED time for the approach;
 2. Cross street traffic is heavy for many hours of the signal-operating day (where the cross street is operating at capacity for almost all hours of the signal-operating day);
 3. Pedestrian use of the crosswalk on the approach street is heavy for almost all hours of the signal-operating day;
 4. Little right-turn demand exists and there is no RIGHT TURN ONLY lane available.
- C. TURNS ON RED *may* be prohibited because of possible adverse public reaction where:
1. A school crossing route passes through the intersection;
 2. There are moderate to high pedestrian volumes.

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