driver performance for type A versus type B markings at this location. At AA I the hypothesis was rejected on weekdays, but could not be rejected on weekends. Hence, at this location, we concluded that there was significant difference in driver performance on the weekdays, but no significant difference on the weekends for type A and B markings.

Next we needed to determine which type of marking produced the better driver performance. According to the function of the street the vehicle turned into, the four locations were put into two corresponding categories (locations AC I and AC II were categorized as the collector streets and locations AA I and AA II as arterial streets). Comparison of daytime and nighttime driver performance for the two categories was examined.

The tabulation below shows that the new marking produces significantly better performance during the night; during the day, it produces significantly better performance only for category II.

Street	Day	Night
Collector	No difference	Type B better
Arterial	Type B better	Type B better

In order to draw an overall conclusion from the selected study locations, a chi-square test was conducted for the number of successes or failures (driver performance as proper or improper). The data consisted of the number of observations falling into either the collector street category or the arterial street category.

We concluded that driver performance with type A markings is independent of the location but that driver performance with type B markings is dependent on the location (i.e., whether the turn is made from an arterial street to another arterial street or to a collector street).

CONCLUSIONS AND RECOMMENDATIONS

After analysis of the data obtained in this study, the following primary conclusions were made:

1. Driver performance did not differ significantly between the two types of markings for locations where turns were made into collector streets;
2. Driver performance differed significantly between the two types of markings on weekdays but not on weekends at AA I;
3. Driver performance differed significantly between the two types of markings at the AA II location;
4. When turning movements were executed into a collector street, driver performance during the day did not differ significantly between the two types of markings;
5. When turning movements were executed into an arterial street, driver performance differed significantly between the two types of markings, and type B marking produced better driver performance;
6. Driver performance differed significantly between the two types of markings at night, and type B marking produced better driver performance; and
7. Driver performance with type A markings were independent of the location chosen.

In general, the results of field observation show that type B marking produces better driver performance and is therefore recommended for use over type A.

Although no accidents occurred during the study, we believe that the type B marking conveys an immediate understanding of the situation that will provide for more uniform traffic flow, will reduce the potential accident rate, and will add to roadway safety in the long run.

REFERENCE

1. Manual on Uniform Traffic Control Devices. Federal Highway Administration, U.S. Department of Transportation, 1971.

Publication of this paper sponsored by Committee on Traffic Control Devices.

Accident Experience With Right Turn on Red

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The right-turn-on-red traffic signal, once used only in the western states, is now permitted in some form in all but one state and the District of Columbia. However, its adoption was slow primarily because of the concern over its safety aspects. As part of a comprehensive study for the Federal Highway Administration, six separate studies on accidents associated with right turn on red were conducted in Virginia and Colorado and in the cities of Denver, Chicago, Dallas, and Los Angeles. In Virginia and Chicago before-and-after studies were performed; in the other locations records were analyzed to determine both the number of accidents and the causes. From the results of the accident analyses, it appears that the accidents related to right turn on red are very infrequent compared with all intersection accidents (0.4 percent versus 3.3 percent). The Chicago and Virginia studies do not reveal a statistically significant increase in intersection accidents, nor do accidents related to right turn on red appear to be less severe than the average intersection accident; no fatalities were found in the entire accident data base. The general conclusion is that right turn on red does not significantly degrade the safety of signalized intersection traffic operation.

Right-turn-on-red (RTOR) signals, previously used only out west, are now permitted in some form in all but one state and the District of Columbia. Use of this control came slowly, primarily because of the concern over potential for causing accidents.

Presumably no collisions should occur if the motorist makes the RTOR maneuver safely by stopping and yielding to the appropriate vehicles and pedestrians in the intersection. However, not all drivers drive safely all the time, and accidents do happen as a result of a host

Table 1. Virginia intersection accidents.

Accident Category	Before RTOR	After RTOR	Increase or Decrease
Fatal	0	0	0
Injury	96	86	-10
Property damage	396	392	-4
Rear end	135	127	-8
Right turn	19	24	+5
RTOG	19	8	-11
Pedestrian	–	1	+1
RTOR	–	16	+16
RTOR injury	–	1	+1
RTOR pedestrian	–	0	0
Total	492	478	-14

of factors involving the driver, the environment, the road, and the vehicle. Furthermore, vehicles negotiating right turns on green (RTOG) also have collisions. RTOR maneuvers are not, a priori, substantially more hazardous than RTOG maneuvers. A key question is whether permitting RTOR significantly degrades the safety of a signalized intersection.

Several studies on RTOR-related accidents (1, 2, 3, 4, 5, 6, 7, 8, 9) tend to support the claim that there are relatively few RTOR accidents compared with all intersection accidents. But these studies were not sufficiently comprehensive or detailed to identify the magnitude of the RTOR accident problem, types of RTOR accidents, or possible causes. Therefore, additional accident experience data were needed to develop a national policy and implementation guidelines.

This accident analysis consisted of six separate studies conducted in Virginia and Colorado and the cities of Denver, Dallas, Chicago, and Los Angeles. Each of the studies was of a different design dictated by the availability of data. For example, in Virginia and Chicago before-and-after RTOR studies were actually performed; in other locations only records of RTOR and intersection accidents could be analyzed. Procedures and results of each accident analysis will be discussed in detail.

VIRGINIA

Since 1972, Virginia has been following the sign-permissive rule for RTOR, but few signalized intersections are signed for RTOR. In fact, as of September 1975 only 8.6 percent of all possible intersections were so signed.

A before-and-after accident analysis was conducted to determine if these RTOR installations have had any effect on safety. Virginia maintains an inventory of RTOR sign installations, so it was possible to identify specific intersections and the dates of installation. From this master list, 29 intersections were selected for a 1-year-before and 1-year-after installation analysis; no significant changes that would have affected accident frequency were found in either the geometrics or the operating conditions.

For each of the 29 intersections, copies of all accident report forms were reviewed for the 2-year study period (1972 to 1974). The following data were extracted:

1. Total number of accidents within 61 m (200 ft) of the intersection,
2. Total number of right-turn accidents for each approach,
3. Total number of rear-end accidents for each approach,
4. Total number of RTOR accidents (by type) for each approach, and
5. Amount of property damage.

Throughout the study, Virginia required all accidents involving a fatality, an injury, or damage assessed at $100 or more to be reported.

All the information on the form, including the verbal description, the diagram, and other pertinent data, was considered. Also, accident rate statistics were determined by average daily traffic (ADT) volumes obtained from the Virginia Department of Highways and Transportation. However, because the traffic volume data were not complete for all the roads or did not correspond directly with the two study periods, valid comparisons of accident rates before and after institution of RTOR could not be made.

The results of the accident data are shown in Table 1. There was a total reduction of 14 accidents (statistically significant at 95 percent confidence using t-test) for the after case. Assuming that all other conditions did not change, this result would indicate that the RTOR signs actually brought about an improvement in safety. However, the reduction in accidents is more likely attributable to some other circumstances, because no RTOR accidents were identified.

As indicated earlier, the number of rear-end accidents was used for both cases to test whether RTOR would reduce or increase this type of accident. In the before case, there were 135 rear-end accidents (27.4 percent of all accidents), whereas, in the after case, there were 127 (26.5 percent of all accidents). This 0.9 percent difference is not statistically significant (chi-square test), and RTOR had no effect on this type of accident.

Another accident type examined was any collision involving a right-turning vehicle. For the before case, there were only 19 such accidents (3.9 percent of all accidents). However, in the after case there were 24 right-turn accidents (5 percent of all accidents). This increase in accidents is not statistically significant, and therefore it cannot be concluded that this increase in right-turn accidents is attributable to RTOR.

Further analysis of the right-turn accidents showed that there were 16 RTOR-related accidents (3.34 percent of all accidents) in the after case. Of these RTOR accidents, none involved pedestrians, only one resulted in an injury, and none resulted in a fatality. The average property damage for the RTOR accidents was $245 as compared to an average property damage of $554 for all accidents and $537 for the before-and-after cases.

The 16 RTOR accidents occurred at only 8 of the 29 intersections, but 1 intersection had 5 accidents, 2 had 3, and 5 had only 1.

COLORADO

The statute allowing an RTOR unless a sign prohibits it has been in effect in Colorado since July 1, 1969. The Colorado Department of Highways has been compiling RTOR accident statistics since 1970. Table 2 shows RTOR-related accident data provided by the state for 1970 to 1975 and includes the yearly figures for all accidents, for two-vehicle accidents at all intersections (signalized or not), and for injury accidents at intersections. In 1973, Colorado began using a short accident report form for property-damage accidents. As a result, we can no longer distinguish between intersection accidents and RTOR-related accidents (however, the short form is not used in the city and county of Denver). Therefore, the reduction in accidents during 1973 and 1974 for intersection accidents is mostly attributable to the fact that intersection accidents involving property damage are not included. It is also likely that this new form has let a few RTOR accidents go unreported.

For the 4 years 1970 to 1973, all accidents increased, but RTOR accidents decreased. However, this trend reversed itself in 1974, when all accidents decreased and the number of RTOR accidents increased to 90 (plus the unknown number not reported on the short form). For 1975, the number of RTOR accidents decreased to 73.

Although we cannot state conclusively that RTOR accidents have decreased over the years, RTOR accidents are obviously only a very small percentage of all accidents or even all intersection accidents. Statewide, RTOR accidents account for less than 0.1 percent of all accidents and about 0.3 percent of all intersection accidents. Also, RTOR pedestrian accidents account for only 0.4 percent (average of 6 years) of all intersection pedestrian accidents. For the years 1970 to 1972 (1973 to 1975 excluded because of the short form), the percentage of RTOR injury accidents was less than the percentage of all intersection injury accidents.

The Colorado Department of Highways also released a breakdown of RTOR accident types and some data on economic losses. A list of the 426 RTOR accidents reported for the years 1970 to 1974 follows.

Accident	Number	Percentage
Pedestrian	12	2.2
Rear end	69	13.6
Broadside	203	40.7
Sideswipe (same direction)	181	36.2
Sideswipe (other direction)	9	1.8
Overtaking turn	8	1.6
Fixed object	3	0.6
Parked car	1	0.2
Bicycle	9	1.8
Ran off road	3	0.6
Overturned	1	0.7
Total	499	100.0

Broadsides and sidewipes same direction accounted for 76.9 percent of all RTOR accidents. These are the accidents that usually occur with RTOR. Although the exact percentage is not known, many of these accident types involved drivers turning right on a red light and failing to yield the right-of-way to opposing traffic turning left on a green arrow (Figure 1b). In 1974, 28 percent of all RTOR accidents were of this type.

The next most frequent type was the rear end, which was 13.8 percent of RTOR accidents. Also, it should be noted that 12 accidents involved pedestrians and 9 involved bicycles. Together, these account for only 4.2 percent of all RTOR accidents.

The economic loss resulting from these 499 RTOR accidents was estimated at $303 440; average vehicle property damage was $218; and the average estimated economic loss per accident was $608. No fatalities attributed to RTOR were reported during the 6 years.

DENVER

In 1974, the city of Denver initiated its computerized accident and traffic data records system and used the 1974 accident data to conduct a citywide RTOR accident analysis. There are 1137 signalized intersections in Denver. At 78 of these RTOR is prohibited on one or more of the approaches, most of which are located downtown where all-pedestrian signal phasing is employed and all vehicle signals are red when all pedestrian signals display WALK.

Denver accident analyses are displayed in Table 3. During 1974, there were 7431 reported accidents at the 1137 signalized intersections, of which only 50 (or less than 1 percent) involved RTOR vehicles. (An intersection accident is defined as any accident occurring within the prolongation of the curb lines or edge of pavement.) Of the 50 RTOR accidents only 3 resulted in injuries, and none involved pedestrians or resulted in a fatality. The average property damage per accident was $275. Seven of the RTOR accidents occurred at locations where the movement is prohibited, and 6 of these occurred at one intersection that will be discussed later.

The statistics displayed on the lower half of Table 3 shed more light on the RTOR accident problem. For each accident statistic described in the first column, the appropriate percentages were calculated for all 1137 signalized intersections, for all 1059 intersections where RTOR is permitted at all approaches, and for the 78 intersections where RTOR is prohibited. Although statistics are shown for all three sets of intersections, we cannot draw any conclusions based on the comparison across the columns, especially for the last two. This is because characteristics of the 78 intersections where RTOR is prohibited differ from those of the remaining intersections. Also, there is a large disparity in the sample sizes (1059 versus 78), which increases the chance of a wrong conclusion. Some of the more important findings are as follows:

1. The 50 RTOR accidents represent only 0.67 percent of all signalized intersection accidents, whereas RTOG accidents accounted for 8.6 percent;
2. RTOR injury accidents were only 0.19 percent of all injury accidents, whereas RTOG injury accidents comprised 4.0 percent; and
3. RTOG pedestrian accidents accounted for 23.2 percent of all pedestrian intersection accidents, but there were no RTOR pedestrian accidents.

The statistics must also be viewed in connection with the exposure factor or, in this case, the percentage of RTOR vehicles. Based on RTOR usage data collected at eight intersections in Colorado, two of which were in Denver, the average percentage of RTOR vehicles to all right turns is about 20 percent. If RTOR were just as hazardous as RTOG, one would expect RTOR accidents to be 20 percent of all right-turn accidents. This is not the case; RTOR accidents account for only 7.7 percent of all right-turn accidents (50 of 690) and only 4.8 percent of all right-turn injury accidents (3 of 62).

It would appear from these statistics that RTOR does not pose a significant safety problem for Denver. All relevant statistics show that RTOR accidents are a small percentage of all accidents, even of right-turn accidents. Furthermore, it is not as hazardous to pedestrians as the RTOG movement.

In an effort to learn more about what causes RTOR accidents, we reviewed each of the 50 RTOR accident reports and field checked some of the sites. Of the 43 RTOR accidents at intersections where the movement is permitted, 3 occurred at one intersection, 2 occurred at each of five intersections, and the remaining 30 accidents occurred at different intersections. At the intersection where 3 occurred, each accident involved an RTOR vehicle using a different approach: 1 resulted from a conflict with an opposing left-turning vehicle, and the other 2 were collisions with cross-street vehicles (see Figure 1).

Each of the 50 accidents was categorized as to conflict type. The most frequent collision (70 percent of the total) was with vehicles moving across the intersection on green. Another accident type occurred frequently (18 percent) when an RTOR vehicle collided with a vehicle making a left turn from the opposite direction on a left-turn phase. In each situation, there was more than one lane on the intersection exit leg. In some cases the RTOR vehicle made a wide turn into the inside lane, while in others the left-turn vehicle made a wide turn into the curb lane.

The geometrics of the intersections did not show any common characteristic that could be considered a contributing factor. However, as indicated above, the presence of a left-turn signal phase for opposite direction traffic adds another conflict potential for the RTOR vehicle and could contribute to RTOR accidents.

The problem of sign visibility appeared to be a significant factor for at least one location. Of the seven accidents where RTOR was prohibited, six occurred at one location on the same approach. This particular intersection happened to have six legs. The no-RTOR signs were post-mounted on the right curb on the near side and the far side of the intersection; traffic signals were both overhead and post-mounted. For each of the six accident reports, the RTOR motorist indicated that he or she was not aware of RTOR prohibition because he or she did not see the sign. An overhead sign placed by the signal head might very well have eliminated the sign detection problem.

Table 2. Colorado statewide RTOR accident data (1970-1975).

Accident Category	1970	1971	1972	1973	1974	1975
Intersection[a]	29 176	31 510	35 257	25 058[b]	20 652	20 374[b]
Intersection injury	6 835	7 085	7 870	7 038	6 142	6 567
Intersection pedestrian	463	482	455	518	435	458
RTOR	93	93	80	70	90	73
RTOR injury	10	16	11	7	8	10
RTOR fatality	0	0	0	0	0	0
RTOR pedestrian	2	2	1	2	1	3
Total	89 599	95 908	110 541	111 425	104 528	110 773
RTOR/total, %	0.10	0.10	0.07	0.06	0.09	0.07
RTOR/intersection, %	0.32	0.30	0.23	0.28	0.44	0.36
RTOR/intersection injury, %	1.36	1.31	1.02	0.99	1.46	1.11
RTOR injury/intersection injury, %	0.15	0.23	0.14	0.10	0.13	0.15
RTOR pedestrian/intersection pedestrian, %	0.43	0.41	0.22	0.38	0.23	0.66

[a] Both signalized and nonsignalized intersections. [b] Introduction of a short form in 1973 accounts for reduction of these categories.

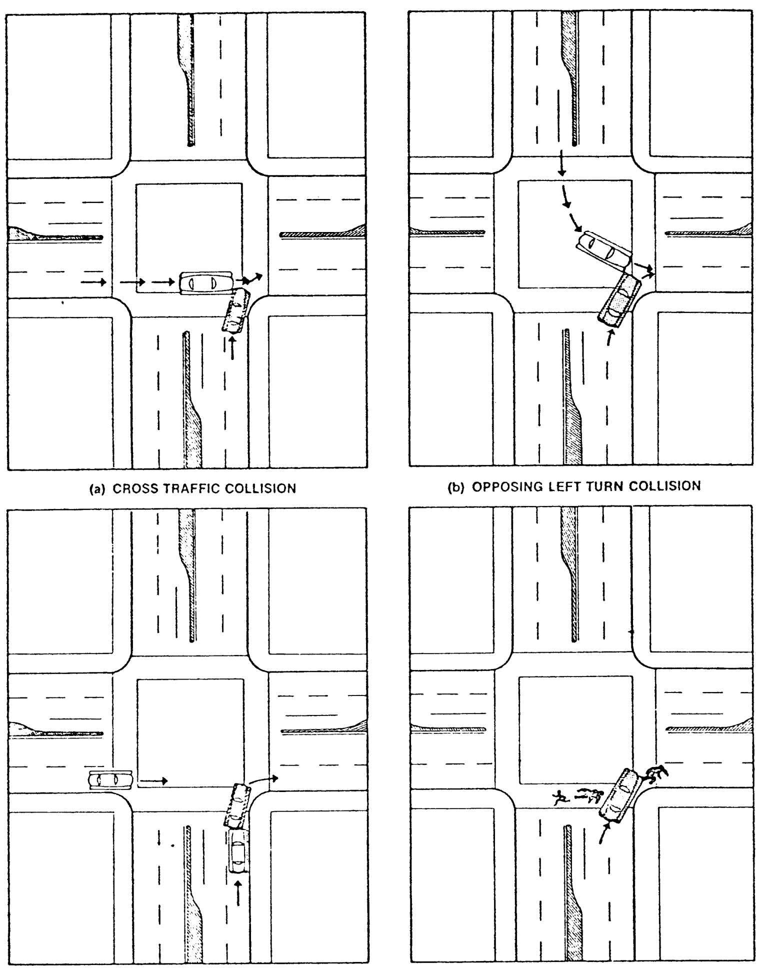

Figure 1. RTOR accident types.

(a) CROSS TRAFFIC COLLISION

(b) OPPOSING LEFT TURN COLLISION

(c) REAR END COLLISION

(d) PEDESTRIAN CONFLICTS

Table 3. Denver accidents in 1974.

Accident Category	Signalized Intersections	RTOR Intersections	Non-RTOR Intersections[a]
RTOG	640	561	77
RTOR	50	43	7
Injury	1555	1454	101
Pedestrian	125	113	12
RTOG injury	59	53	6
RTOR injury	3	2	1
RTOG pedestrian	29	28	1
RTOR pedestrian	0	0	0
Total	7431	6676	755
RTOR/total, %	0.67	0.69	0.93
RT/total, %	9.30	9.10	11.10
RTOG/total, %	8.60	8.40	10.20
Injury/total, %	20.90	21.80	13.40
RTOG injury/total injury, %	4.00	3.80	6.90
RTOR injury/total, %	0.04	0.03	0.01
RTOR injury/total injury, %	0.19	0.14	1.00
Pedestrian/total, %	1.70	1.70	1.60
RTOG pedestrian/total pedestrian, %	23.20	24.80	8.40

[a]Of the 1137 signalized intersections in the city, 78 have RTOR prohibitions. Of these, 54 are located downtown where an all-pedestrian signal phasing is employed.

DALLAS

The city of Dallas has had the RTOR rule since August 1973 when Texas adopted the law. Because of this change, it was possible to conduct a 1-year before-and-after accident analysis in the course of this study. However, because of the difficulty of extracting the accident data and then defining RTOR accidents, the analysis was limited to pedestrian accidents. At the request of the project staff, Dallas provided a summary listing of pedestrian accidents that occurred at intersections throughout the city.

Included on the summary listing was a column that indicated the appropriate traffic control (signal or stop sign) and a column indicating the direction analysis of the vehicle (right, straight, left, or unknown). These summary listings were provided for 1972 to 1974, allowing us to extract pedestrian accidents at signalized intersections during the 2-year study period. The summary listing did not reveal whether or not the accident involved an RTOR vehicle, but from the police accident reports for the after period this determination was possible.

Dallas has approximately 1000 signalized intersections, of which 86 have no-RTOR controls at one or more approaches. Some, but not all, of these restrictions are because of pedestrian conflicts.

The numbers of pedestrian accidents that occurred at all intersections for 1972, 1973, and 1974 were 50, 55, and 53 respectively, and at all signal-controlled intersections 23, 17, and 17. As shown by the data, intersection pedestrian accidents over the 3-year period have been fairly consistent.

Table 4 shows the comparative results for 1 year, both before and after the RTOR rule became effective. The data revealed a slight increase in pedestrian accidents at all intersections as well as at signalized intersections, but these increases are not statistically significant at the 95 percent confidence level.

Of the 18 pedestrian accidents that occurred at signalized intersections during the after period, only 1 involved a right-turning vehicle (the same as for the before period). The narrative portions of the police accident report forms indicated that only 1 pedestrian accident (that noted as a right-turning accident) could have involved an RTOR vehicle. The data in the tables suggest that RTOR has not caused any increase in pedestrian accidents in Dallas.

CHICAGO

On January 1, 1974, the RTOR law became effective for the state of Illinois. Before then the state had a sign-permissive rule. This change afforded the opportunity to analyze accidents at numerous intersections in Chicago under the two basic RTOR rules as compared to RTOG only.

The accident analysis was built on a study partially completed by the Chicago Traffic Engineering Department. The city selected 97 intersections to determine if the sign RTOR rule causes accidents. These intersections were a geographic sampling distributed throughout the city. Later, two intersections were eliminated because the permissive RTOR signs were removed. These study intersections represent about 4 percent of nearly 1460 signalized intersections.

Chicago collected accident data for a 9-month period (April through December 1972) during which RTOR was not allowed and for the same 9 months of 1973 after RTOR signs had been installed. Because the current generally permissive RTOR rule became valid on January 1, 1974, the city could not obtain a full year of data; therefore, it completed its analysis at that point.

Accident data were collected for the same 95 intersections for a full year under the generally permissive rule. Unfortunately at 17 of the experimental sites no-RTOR signs were installed where RTOR had previously been allowed, thereby reducing to 78 the total number of intersections that could be compared.

In addition to the accident data collection, RTOR usage counts were made at a sample of the intersections in order to determine an average RTOR exposure factor. Later the city did this at all 97 intersections for the analysis and at 10 of the intersections for the expanded analysis under the generally permissive rule.

Table 5 shows the summary accident statistics for the 95 intersections for 9 months in 1972 without RTOR and 9 months with RTOR by sign in 1973. The before-and-after accident data show that there was a statistically significant increase of 110 accidents (13.3 percent). However, for the same two periods, there was a 10.5 percent increase (21 315 to 23 595 or 2280) in total signalized intersection accidents for all 2460 intersections. Therefore, this increase in total accidents cannot be attributed solely to the RTOR feature.

There was a very significant increase, 52 percent, in right-turn accidents. In the before case the 91 right-turn accidents accounted for 11 percent of all accidents; in the after case the 138 right-turn accidents were 14.7 percent. On a citywide basis, there was a 16.1 percent increase (1792 to 2080) in right-turn accidents at all signalized intersections, 27 instances of which involved RTOR. These 27 RTOR accidents represented only 2.9 percent of all the intersection accidents but nearly 20 percent of all right-turn accidents.

Pedestrian accidents increased by 42.5 percent (40 to 57). Furthermore, it was found that of the 11 right-turn vehicle-pedestrian accidents after the RTOR signs were installed 5 involved an RTOR maneuver.

While the RTOR signs were in place, the city conducted a 1-h RTOR count at each intersection. The degree of RTOR usage varied from a low of 3.6 percent of all right turns to a high of 40.6 percent; the average was 14.8 percent. As noted before, the RTOR accidents accounted for 20 percent of all right-turn accidents. Therefore, with RTOR averaging about 15 percent of the total right-turn volumes, the accident statistics for these intersections indicate that RTOR had a slightly higher accident rate than RTOG.

Table 6 shows similar accident data for 78 of the 95 intersections under three RTOR conditions [RTOR prohibited (1972), RTOR allowed with a sign (1973), and RTOR allowed without a sign (1974)]. The sample size was reduced for this three-way analysis because at the remaining 17 intersections no-RTOR signs were installed at various times during the 1974 9-month study period. The lower half of the table shows various accident statistics derived from the data in the upper half.

In comparing the 1972 no RTOR with the 1973 RTOR with sign, we found the same results for the 78 as for the 95 intersections. The percentage of RTOR accidents of all accidents (3.4 percent) is slightly higher for the smaller sample set than the larger set (2.9 percent), because the right-turn pedestrian accidents (including RTOR pedestrian accidents) were all located at the 78-intersection subset.

The accident distribution was quite similar for the last period (1974) with generally permissive RTOR when compared to 1973 with sign-permissive RTOR. There were slight decreases in total accidents and RTOR accidents but neither was statistically significant. The only significant difference was a decrease in total pedestrian accidents in 1974, but the levels of right-turn and RTOR pedestrian accidents were comparable for the two periods.

To determine how the 1974 RTOR accident statistics might have been affected by RTOR usage, 1-h counts were made at 10 of the intersections. Each of these counts was made at the same hour and day of the week as the 1973 count under the RTOR sign. For these 10 intersections, the RTOR usage (RTOR volume of total right turns) varied from a low of 9.2 percent to a high of 35.8 percent; the average was 24.4 percent. For the same 10 intersections, the average RTOR usage was 19.9 percent under the sign rule. Although statistically inconclusive, it appears that there were fewer RTOR-related accidents under the general rule than under the sign rule, even with a higher percentage of RTOR maneuvers. This reduction in RTOR accident frequency was probably due more to driver experience with the maneuver than to the degree of safety under either rule.

Table 4. Dallas pedestrian accidents before and after RTOR.

Accident Category	Year Before RTOR	Year After RTOR	Increase	Percentage Change
All intersections	48	55	7	14.6
Signalized intersections	16	18	2	12.5
Signalized intersections involving right-turning vehicles	1	1	0	0.0

Table 5. Accidents at 96 Chicago intersections with and without RTOR.

Accident Category	No RTOR 1972	RTOR With Sign 1973	Increase or Decrease	Percentage Change
RT	91	138	+47	51.6[a]
RTOG	91	111	+20	22.0[a]
RTOR	–	27	+27	–
Pedestrian	40	57	+17	42.5
RTOG pedestrian	7	6	-1	-14.3
RTOR pedestrian	–	5	+5	–
Total	826	936	+110	13.3[a]

[a]Statistically significant at 95 percent confidence level.

Table 6. Accidents at 78 Chicago intersections.

Accident Category	No RTOR 1972	RTOR With Sign 1973	RTOR Without Sign 1974
RT	65	103	101
RTOG	65	79	80
RTOR	–	24	21
Pedestrian	29	47	24
RTOG pedestrian	5	6	3
RTOR pedestrian	–	5	6
Total	618	709	694
RT/total, %	10.5	14.5	14.6
RTOR/total, %	–	3.4	3.0
RTOR/RT, %	–	23.3	20.8
Pedestrian/total, %	4.7	6.6	3.5
RTOG pedestrian/total pedestrian, %	17.2	12.8	12.5
RTOR pedestrian/total pedestrian, %	–	10.6	25.0

LOS ANGELES

Los Angeles has allowed RTOR at all intersections unless otherwise posted since 1947. RTOR is rarely prohibited in Los Angeles; in fact, out of approximately 3300 signalized intersections where right turns can be made, only 33 (1 percent) have a no-RTOR sign on one or more of the approach legs.

For several years, the city has had a computerized traffic accident information system that has a wide range of accident-analyzing capabilities. Included in the system are not only accident data but also geometric, signal control, and traffic volume data. As a matter of procedure, RTOR accidents are coded into the computerized record system from the accident report. With this information it was possible to conduct a finer analysis of RTOR accidents throughout the city. This analysis was based on accident files for 1973 and 1974. All RTOR accidents were identified by a computer sorting routine in the Los Angeles Traffic Engineering Department. The accuracy of RTOR accident reports would therefore depend on the reliability of police officers making the report and the clerk coding the accident into the computer file.

For 1973 and 1974 a total of 287 accidents were identified as being RTOR related. This figure represents only 0.69 percent of all 41 316 accidents that occurred at 3235 signalized intersections where RTOR can legally be made.

Table 7 shows the comparison of the RTOR accidents with all signalized intersection accidents for various classifications. With respect to severity, it was found that there were no fatal accidents involving an RTOR vehicle. However, nearly 50 percent of the reported RTOR accidents involved an injury, as is the case for all intersection accidents. The percentage of injury accidents is high because as many as two-thirds of all property-damage-only (PDO) accidents go unreported (the California vehicle code specifies that all accidents valued at $100 or more shall be reported, but this requirement is not commonly known or heeded). There were no doubt more RTOR accidents than the 287 identified in this analysis. However, it is likely that RTOR accidents as a percentage of total accidents would be nearly the same as 0.69 percent, since PDO accidents at other intersections also go unreported.

The accidents were categorized into seven types as noted in Table 7. It was found that, of the 287 RTOR accidents, 54 (18.8 percent) involved a pedestrian. When compared to the total of 1487 pedestrian accidents occurring within a 30-m (100-ft) distance of the signalized

Table 7. Los Angeles RTOR accidents versus all signalized intersection accidents (1973-1974).

Classification	Total Intersection Accidents: Number	Total Intersection Accidents: Percentage	RTOR Accidents: Number	RTOR Accidents: Percentage
Accident severity				
Fatal	154	0.4	0	0.0
Property damage	19 796	46.6	144	50.2
Injury	22 474	53.0	143	49.8
Accident type				
Pedestrian	1 487	3.5	54	18.8
Run off road, overturned, parked vehicle, fixed object, other non-collision	5 728	13.5	23	8.0
Right turn all types	407	1.0	94	32.8
Left turn all types	9 969	23.5	4	1.4
Right angle, rear end, sideswipe, head on	21 798	51.3	63	22.0
U-turn or other multivehicle	2 147	5.1	49	17.0
Alley	886	2.1	0	0.0
Lighting conditions				
Day	28 374	66.9	227	79.1
Dusk or dawn	754	1.8	1	0.3
Dark	13 296	31.3	59	20.6
Street type				
Local-local	413	1.0	4	1.4
Collector-local	49	0.1	1	0.3
Collector-collector	116	0.2	1	0.3
Minor arterial-local	433	1.0	2	0.7
Minor arterial-collector	818	1.9	3	1.0
Minor arterial-minor arterial	1 124	2.6	7	2.4
Principal arterial-local	4 876	11.5	25	8.7
Principal arterial-collector	5 626	13.4	35	12.2
Principal arterial-minor arterial	10 708	25.3	77	26.8
Principal arterial-principal arterial	18 224	43.0	132	46.0
Number of legs				
3 T or Y	3 651	8.8	21	7.7
4	32 707	79.2	220	80.3
>4	4 963	12.0	33[a]	12.0
Signal operation				
Two phase	37 338	88.0	243	84.7
Three phase, leading left	2 393	5.6	24	8.4
Three phase, lagging left	724	1.8	3	1.0
Multiphase	1 943	4.6	17	5.9

[a] Does not total 287.

intersections, the RTOR pedestrian accidents account for only 3.6 percent. However, the 18.8 percent is significantly greater than the 3.5 percent for all pedestrian accidents compared to all intersection accidents.

As expected, the remaining distribution of RTOR accident types is dissimilar to that of all intersection accidents, since an RTOR accident is commonly coded as a right-turn accident. In this case, nearly 33 percent of all the RTOR accidents were classified as right-turn accidents. However, the true percentage was probably higher, because of the many RTOR accidents identified in the other categories. It is interesting to note that, of 407 accidents classified as right turn all types, 94 (23 percent) involved an RTOR accident. RTOR volume data were not available for Los Angeles, but in Berkeley Ray found an average of 18 percent of the right-turn volumes were RTOR maneuvers (4). If we assume that this percentage is applicable to Los Angeles, then it would appear that RTOR accidents as a percentage of all right-turn accidents (23 percent), while slightly higher, is similar to the RTOR volume percentage.

The accidents were classified into three lighting condition periods: day, dusk or dawn, and dark (street lights and no street lights). The results show a statistically significantly higher percentage of RTOR accidents during daylight than of all accidents, meaning that RTOR is no more dangerous at night than in day, and, therefore, there would be no reason to prohibit the movement during the night.

Table 7 also gives the accident distribution by street type (local, collector, minor arterial, and principal arterial). RTOR accidents occurred at intersections of different street types in nearly the same proportion as total intersection accidents. The greatest spread in percentages was for the principal arterial-principal arterial (43 percent for all versus 46 percent for RTOR accidents), but this difference is not statistically significant (chi-square, one-way classification). The greatest number of RTOR accidents occurred at the intersections of two principal arterial roads, which is probably a direct function of the traffic volumes.

Another breakdown of accidents was by the number of approach legs to the intersection (three T or Y, four, and more than four). Of course, the vast majority of both RTOR and all accidents occurred at four-legged intersections, but, somewhat surprisingly, the percentage distributions are nearly identical. However, note that 12 percent of the RTOR accidents occurred at intersections with more than four approaches. Many of the no-RTOR signs are installed at these types of approaches, but as a general rule the city does not prohibit RTOR at this type of intersection.

Still another classification was by signal operation mode. The many modes were grouped into four types: two phase, three phase with leading left, three phase with lagging left, and multiphase. The purpose of this classification was to determine if complex signal phasing had any effect on RTOR accident frequency. Once again, the two percentage distributions are comparable and not statistically different. The majority of RTOR accidents, nearly 85 percent, occurred where there was a simple two-phase signal operation.

The final comparative accident distribution analysis

Table 8. RTOR accidents at several locations.

RTOR Rule	Location	Study Year	Signalized Inter-sections	Inter-section Accidents	RTOR Accidents		Pedes-trian Accidents	RTOR Pedestrian Accidents		
					Number	Percentage		Number	Percentage of Pedestrian Accidents	Percentage of RTOR Accidents
Generally permissive	Los Angeles	1973-1974	3235	41 316	287	0.70	1487	54	3.6	18.8
	Denver	1974	1059	7 431	50	0.70	125	0	0	0
	Dallas	1973-1974	1000	–[a]	–[a]	–[a]	18	0	0	0
	Chicago	1974	78	694	21	3.0	24	6	25.0	28.6
	San Francisco	1953-1955	75	3 328	12	0.4	14	4	29.0	33.0
	Portland	–[a]	–[a]	52 677	253	0.5	–[a]	20	–[a]	7.9
	Jacksonville	–[a]	405	1 756	13	0.7	–[a]	2	–[a]	15.4
	Dade County	–[a]	29	700	9	1.3	–[a]	0	0	0
	Omaha	1971-1972	26	497	11	2.2	–[a]	0	0	0
	Salt Lake City	–[a]	24	600	8	1.3	–[a]	0	0	0
Sign permissive	Chicago	1973	95	936	27	2.9	57	5	8.8	18.5
	Columbus	1973	12	415	11	2.7	–[a]	0	0	0
	Virginia	1973	29	478	16	3.3	1	0	0	0

[a]Unknown.

Table 9. RTOR injury accidents versus all intersection injury accidents.

Location	Total	Injury		RTOR	RTOR Injury	
		Number	Percentage		Number	Percentage
Colorado	35 510	7 870	22	80	11	14
Denver	7 431	1 555	21	50	2	4
Los Angeles	42 424	22 474	53	287	143	50
Virginia	478	86	18	16	1	6

was a classification of pedestrian accidents by actions, that is, whether the pedestrian was crossing the intersection legally with the signal or illegally against the signal. Below we show the number and percentage of pedestrian accidents occurring as pedestrians crossed with or against the signal.

Accident Category	Crossing With Signal		Crossing Against Signal	
	Number	Percentage	Number	Percentage
All	896	83	187	17
RTOR	53	95	3	5

The total number of accidents does not equal that noted in the table because some accidents could not be classified in either category. In nearly all the RTOR pedestrian accidents, the pedestrian was crossing the intersection with the signal, presumably in the crosswalk immediately in front of the RTOR vehicle. Only three accidents involved an RTOR motorist hitting a pedestrian crossing against the signal, in this case presumably on the crosswalk. By contrast, for all the pedestrian accidents there were more involving the pedestrian crossing against the signal.

The next analysis was to examine more closely those intersections where RTOR accidents occurred. The 287 identified RTOR accidents for the 2-year period occurred at 267 intersections throughout the Los Angeles area. These intersections represent only 8 percent of the 3235 signalized intersections where RTOR can be made. Only 1 intersection had 3 RTOR accidents during the 2-year period and 18 had 2 accidents, with the remaining 248 accidents occurring at different intersections.

It was not possible to make an on-site investigation of each site, but those intersections where more than one RTOR accident occurred were field checked for any particular feature that may have caused these intersections to experience more than one RTOR accident. Factors considered were number of approach lanes, number of cross-street lanes, average speeds of cross-street traffic, cross-street volume, sight distance, pedestrian activity, and parking on cross-street approach.

If these intersections were particularly hazardous for RTOR movements, then logically they should have had some common geometric or operational feature. However, all the factors were found to vary widely. Approach lanes varied from one to five and cross-street through lanes from one to four. Surprisingly, none of the intersections had cross-street speeds greater than 72 km/h (45 mph), and most were between 40 and 64 km/h (25 and 40 mph). Cross-street volumes expressed in 24-h ADT also ranged considerably from 2000 to 35 000. Although sight distance measurements were purely subjective, only two intersections were noted as having restricted (poor) sight distance.

SUMMARY OF RTOR ACCIDENT EXPERIENCE

The preceding sections discussed RTOR accidents at six different locations. As noted in the introductory remarks, each study was different in scope and methodology. Nonetheless, the results of the separate analyses can be synthesized to provide some general observations regarding the accident problem associated with RTOR.

RTOR Accident Frequency

From the results of our accident analysis and those reported by others, it appears that RTOR accidents are very infrequent. Shown in Table 8 are the overall RTOR accident statistics for 13 different locations using data developed in this study and reported by other researchers. The percentage of RTOR accidents (all types) to all accidents occurring at the specified number of signalized intersections for the generally permissive rule range from a low of 0.4 in San Francisco in a 1953 to 1955 study by Ray to a high of 3.0 for the 78 test intersections in Chicago; the weighted average is 0.61 percent (4).

For the three locations with the sign-permissive rule, there was less variability in the RTOR percentage statistics; the lowest figure was 2.7 percent for Columbus, Ohio, and the highest was 3.3 percent for the 29 locations in Virginia. The weighted average is 2.95 percent, which differs considerably from the 0.61 percent for the generally permissive rule states. This disparity might indicate that the sign-permissive rule is more dangerous than the generally permissive rule. However, this conclusion is not statistically correct, because the sample size was so much smaller for the sign-permissive rule than for the generally permissive. Also, in each of the three sign-permissive rule locations, the RTOR accident statistics represent initial experience with the maneuver. One might expect that RTOR accidents would decrease in frequency as motorists became more familiar with its operation.

Also included in Table 8 are the RTOR pedestrian accidents shown as a percentage of all pedestrian accidents and as a percentage of all RTOR accidents. For the first of the two statistics, there was a wide variability with a low of 0.0 percent found in five different locations with the generally permissive rule to a high of 29 percent found in Ray's study in San Francisco. The weighted average is 3.75 percent, which was strongly influenced by the Los Angeles data. For the second statistic, it was found that where there were some pedestrian RTOR accidents the percentage ranged from 7.9 to 33.0 with a weighted average of 14.7.

For the sign-permissive rule, only Chicago provided any significant data showing that 8.8 percent of all intersection pedestrian accidents are related to RTOR, and 18.5 percent of all RTOR accidents involve pedestrians.

Before-and-After RTOR Comparisons

It was feasible to make only limited comparisons of accident statistics before and after RTOR, and the results obtained were mixed.

In Chicago, total accidents, right-turn-related accidents, and pedestrian accidents all rose at the 95 study intersections after sign-permissive RTOR was instituted, but there were only 27 accidents involving RTOR vehicles (or about 3 percent) out of a total of 936. Moreover, total intersection accidents citywide in Chicago rose that same year by nearly the same percentage as the 95 study intersections where RTOR had been instituted, so it is difficult to attribute much of the increase at the study locations to the change in RTOR rule. Chicago then switched to the generally permissive RTOR rule, and at 78 intersections that previously had sign-permissive RTOR not much change occurred in overall accident frequency. However, pedestrian accidents dropped sharply, more than offsetting the rise in accidents in the previous year under the sign-permissive RTOR rule.

A similar study was conducted at 29 intersections in Virginia, where a change was made from no RTOR to the sign-permissive RTOR. Yearly total accidents decreased slightly from 492 to 478 (statistically significant), but this decrease cannot be attributed to the change in the RTOR rule. Right-turn accidents rose insignificantly from 19 to 24, 16 of which involved RTOR maneuvers. Only one of the RTOR collisions resulted in an injury, and none involved pedestrians.

In Dallas the generally permissive RTOR rule was adopted in August 1973 as part of the statewide change, but it was feasible to study only the effects on pedestrian accidents. Comparing the 1-year periods before and after the RTOR rule change, pedestrian accidents increased slightly (but statistically insignificantly) from 16 to 18. During both the year before and the year after the RTOR rule change only one pedestrian accident involving a right-turning vehicle occurred, and there was no indication of whether RTOR maneuvers were involved.

RTOR Accident Severity

Based on the results of the accident analyses, RTOR-related accidents are less severe than the average intersection accident. For the six locations studied, there were no fatalities as a result of RTOR accidents.

Table 9 shows the percentage of RTOR injury accidents compared to all injury accidents at signalized intersections (10). In each case the percentage of RTOR injury accidents was smaller than that of all injury accidents. The high percentage for Los Angeles (50 percent) is explained by the many PDO accidents that go unreported.

RTOR accidents also tend to have less property damage compared to all intersection accidents. For example, in Virginia the average amount of property damage (as reported) was $538 for all accidents compared to only $229 for RTOR accidents. This latter figure compares favorably with the average property damage of $218 for RTOR accidents reported in Colorado.

RTOR Accident Types

Several distinct types of accidents appear to be associated with RTOR. Illustrated in Figure 1 are four prominent types of RTOR conflicts: rear end, opposing left turn, cross street, and pedestrian.

The most common RTOR accident type occurs when an RTOR vehicle collides with a vehicle moving on green on the cross street (Figure 1a). Sixty-five percent of the reported RTOR accidents in the studies could be categorized under this type, which usually occurs when an RTOR motorist either fails to see the approaching vehicle or perceives a wider gap than is required to make a safe maneuver. These accidents are usually caused by driver error, although limited sight distance can be a contributing factor.

Another frequent type of RTOR accident involves an RTOR vehicle colliding with a vehicle making a left turn from the opposite approach on a left-turn phase (Figure 1b). Of all RTOR accidents, 18 percent were of this type. In this situation, an RTOR motorist looking to his or her left for oncoming cross-street traffic may not be aware of a conflict with left-turning vehicles moving on a separate phase. This conflict can be more serious if there is only one lane to turn into. Where there are multiple departure lanes, the turning vehicles can avoid collision. The accident forms, however, indicated that these types of accidents occurred with multiple lanes as well as with single departure lanes. Prohibiting RTOR at all locations with a left-turn phase should preclude these accident types from occurring. However, because of the randomness and infrequency of these accidents, it would not be practical to prohibit the movement at all such locations.

The third type of RTOR accident is the rear end (Figure 1c). These occur when a vehicle in the process of making an RTOR stops abruptly and is hit in the rear by the following vehicle. This type of accident accounted for 5 percent of all identified RTOR accidents. Because these typically result from driver error, there does not appear to be any way to eliminate them.

The fourth major type of accident is an RTOR vehicle hitting a pedestrian crossing the intersection. As shown in Table 8, the percentage varied widely from 0 to 33 percent. In most cases, the pedestrian was hit while crossing on green in the crosswalk immediately in front of the turning vehicle. However, in a few instances a pedestrian was hit while crossing on a red signal (which is illegal in most states) in the crosswalk on the lane the vehicle is turning into.

In addition to these four major types of RTOR accidents, there were two others that were very infrequent.

1. Two RTOR vehicles sideswipe. Sometimes two vehicles collided while making an RTOR simultaneously when there were double right-turn lanes, or when one of the vehicles used the shoulder.
2. The RTOR vehicle induces an accident. In two cases the RTOR vehicle, although not involved in the accident, created a situation that resulted in an accident. Once the cross-street vehicle collided with another cross-street vehicle to avoid hitting the RTOR vehicle. In another case (which happened in Ohio and was brought to our attention), the RTOR vehicle apparently induced a following vehicle to cross the intersection on red resulting in an accident with a cross-street vehicle coming from the opposite direction. This latter accident resulted in a fatality, the only one during the whole course of study.

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REFERENCES

1. W. Marconi. Right Turn on Red—One View. Traffic Engineering, May 1973, p. 7.
2. R. L. May. RTOR: Warrants and Benefits. Purdue Univ., Joint Highway Research Project 74-14, Aug. 1974.
3. M. B. Meyer. Right Turn on Red Signal Study. Cedar Rapids Traffic Engineering Department, Iowa, Aug. 1970.
4. J. C. Ray. The Effect of Right-Turn-on-Red on Traffic Performance and Accidents at Signalized Intersections. Institute of Transportation and Traffic Engineering, Univ. of California, Berkeley, student research paper, May 1956.
5. Review—Right Turn on Red. Wichita Traffic Engineering Division, Kansas, Aug. 1971.
6. Right Turn on Red. Committee 3M(65), ITE, May 1968.
7. Right Turn on Red Accident Study. Office of Traffic Engineering, Minnesota Highway Department, Final Rept., 1971.
8. M. R. Parker, R. F. Jordan, Jr., J. A. Spencer, M. D. Beale, and L. M. Goodall. Right Turn on Red. Virginia Highway and Transportation Research Council, Report to the Governor and General Assembly of Virginia, Sept. 1975.
9. Some Right-Turns-on-Red Facts. Oklahoma City Department of Traffic Control, Nov. 1971.
10. H. W. McGee. Right-Turn-on-Red: Current Practices and State-of-the-Art. Federal Highway Administration, Rept. FHWA-RD-75-5, Oct. 1974.

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Abridgment

Driver Behavior During the Yellow Interval

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Every driver has experienced the anxiety of approaching an intersection as the signal turns yellow. The driver must then decide quickly whether to stop or to go through before the signal turns red. The change period is one of the most important and least studied intervals of the signal cycle.

This investigation has a threefold purpose: to provide an understanding of driver characteristics during the yellow interval, to determine the ability of drivers to stop in time, and to present a method for determining the length of the clearance interval for urban intersections. The data collected in this study of one intersection help answer the following questions: What do drivers do when the signal changes to yellow? How fast a deceleration rate will drivers accept when the signal changes to yellow? How long should the clearance period be to satisfy the drivers' needs?

RESULTS

Probability of Stopping as a Function of Distance

At the intersection studied, 816 close-decision vehicles were recorded. The probability of stopping was plotted against the cube root of the distance from the stop line at the instant the signal turned yellow, and the results are shown in Figure 1.

Probability of Stopping as a Function of Approach Velocity

The total distribution was stratified in order to obtain distributions of the probability of stopping for vehicle speeds of 16.1, 24.1, 32.2, and 40.2 km/h (10, 15, 20, and 25 mph). From these distributions the probability of stopping given distance from the stop line was deduced.