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Public Good Relative to Right-Turn-on-Red in South Carolina and Alabama

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The effects of South Carolina's and Alabama's right-turn-on-red (RTOR) laws on highway safety, fuel consumption, and air pollution were investigated. Accidents at signalized intersections involving right-turning vehicles (RT) before and after the passage of RTOR laws in both states were studied and compared with accidents at signalized intersections that did not involve vehicles making a right turn (NRT). Data for two years before and three years after the effective date of South Carolina's RTOR law were analyzed; the Alabama data included three years before and five years after. The findings of this study indicated that the rate of change of RT property damage accidents in South Carolina was significantly higher for RT property damage accidents in the after period than the corresponding change for NRT accidents. The rate of change of RT property damage accidents in Alabama was not found to be significantly higher for RT accidents in the after period than the corresponding change for NRT accidents. The findings of this study also indicated that there was no significant difference in the rates of change of RT fatality or injury accidents when compared with the corresponding change for NRT fatality or injury accidents in both South Carolina and Alabama. This study could find no evidence that pedestrian accidents in either state increased as a result of RTOR operations. A further analysis was performed on fuel and travel time savings resulting from RTOR operations. Based on the findings of this study and the benefits estimated, no changes are warranted in either Alabama's or South Carolina's RTOR law, and the laws should remain in effect.

Right-turn-on-red (RTOR) is now permitted in some form in all of the states. Adoption of RTOR was accelerated in 1975 after Congress passed the Energy Policy and Conservation Act, which requires each state to develop a state energy conservation plan. One of the requirements of this plan is state adoption of RTOR. In addition, an FHWA study (1) undertaken after the passage of the Conservation Act reported that the RTOR feature would increase intersection capacity, reduce delay especially for right-turning vehicles, and reduce fuel consumption and automobile emissions. The study further reported that the number of accidents as a result of the adoption of RTOR would be insignificant.

Despite the results of many other studies supporting the fuel savings from RTOR and supporting the general conclusion that RTOR does not significantly lower the safety of signalized intersections (SIs), RTOR operations have recently become the subject of much scrutiny. Vast amounts of data have been generated both in favor of and against RTOR. A study by Zador (2) reported that the increase in the overall frequency of RTOR crashes in the states that adopted permissive RTOR laws exceeded by more than 20 percent the comparable change in states that retained the same laws. Furthermore, this study reported that pedestrian accidents had increased substantially after the adoption of RTOR. The increase among children was reported as 30 percent, the increase among adults was about 100 percent, and among the elderly the increase was about 110 percent. Computer files of all accidents reported to the police were obtained from six study states (New Jersey, Oklahoma, South Carolina, Tennessee, Virginia, and Wisconsin) and three comparison states (Maryland, Texas, and Washington) for 1974-1977 for use in this study. The RTOR accident experience in the comparison states may not be comparable with the data from the study states because of possible differences in drivers and demographic factors. The data from half of the comparison states were for an after period of 1 year or less. This is probably not sufficient time for the drivers to adjust to the effects of the change in the law.

More recently, Hochstein (3) stated that RTOR accident data, fuel savings, psychological impact, installation and maintenance costs, and legal liabilities have not been researched thoroughly. Hochstein made the point that the federal bureaucracy entered the engineering domain with rules and regulations to promulgate a traffic policy based on questionable research and data. Hochstein based most of his remarks on data obtained from the Zador report (2).

Inasmuch as the RTOR traffic operations feature continues to be a controversial issue, we decided to review the effects of RTOR in South Carolina and Alabama. These states were chosen because a sufficient time had elapsed since the passage of the law, and both states had accident data readily accessible through the Records Analysis for Problem Identification and Definition (RAPID) System (4).

South Carolina passed RTOR into law on February 15, 1977, and the law became effective on May 16, 1977. Similarly, in Alabama the RTOR law was passed and became effective on August 18, 1976. In both cases this law permitted right-turn-on-red except at locations where it was specifically prohibited by traffic signs. Before to the passage of the law RTOR was sign permissive (i.e., prohibited except at locations where it was permitted by traffic signs).

OBJECTIVE AND METHOD OF STUDY

The objective of this study was to examine the characteristics of right-turn accidents at signalized intersections and to determine if the RTOR traffic operations measure as passed into law caused a significant increase in traffic accidents in South Carolina and Alabama.

Accident data used in this study were obtained from computer tapes of traffic collisions reported in South Carolina during 1976-1980 and in Alabama during 1974-1981. The RAPID software (4) was used for retrieval of data from the computerized records. Because of a possible bias resulting from the inability of the accident investigator to determine whether a particular accident involving a right turn at a signalized intersection (SI) occurred during a red or green phase, the following classifications of accidents were used:

RT--An accident occurring at a SI with a functioning signal in which at least one of the involved vehicles was turning right.

NRT--An accident occurring at a SI with a functioning signal in which none of the involved vehicles were turning right.

These classifications permitted an analysis of the frequency of accidents at SIs involving right turns and the frequency of accidents not involving right turns both before and after the passage of the RTOR laws.

For the purpose of analysis, the period 1976-1977 will be considered as the before period in South Carolina, thus allowing the motorist 7.5 months after the effective date of the RTOR law for recognition and acclimation to the change. The years 1978-1980 will be the after period for South Carolina. Similarly, the years 1974-1976 were taken as before and the interval 1977-1981 was considered as the after period for Alabama.

ANALYSIS

Accident Experience

Accident frequencies for RT accidents and NRT accidents at SIs are given in Tables 1 and 2. By using the geometric mean the average percentage of change was calculated for each type of accident. For example, the geometric average change for the first row of Table 1 is given by

$$g = [(76{,}492/72{,}216) \times (81{,}609/76{,}492) \times (80{,}674/81{,}609) \times (74{,}936/80{,}674)]^{1/4} - 1 = (74{,}936/72{,}216)^{1/4} - 1 = 1.0093 - 1 = 0.0093 = 0.93 \text{ percent} \quad (1)$$

The results from Tables 1 and 2 show that the average change for all reported accidents in South Carolina was 1.15 percent as compared with 4.44 percent for NRT accidents and 7.97 percent for RT accidents. These percentages were, respectively, 0.52, -0.66, and -2.39 for Alabama. Thus, the data in Table 1 for South Carolina show a slight upward trend for the 5-year span 1976-1980 and for Alabama the trend is positive for all accidents but downward for NRT and RT categories. Because data for South Carolina were not sufficient to examine trend and seasonality, a simple before-after χ^2 test was conducted. The results are given in Table 3. As discussed previously, the 2-year before period actually includes 7.5 months of operations after the effective data of the RTOR law (May 16, 1977), thus the motorist is given time to become aware of and acclimated to the change.

The null hypothesis tested was that no difference exists in the change (from before the law to after) of accident frequencies at SIs for RT and NRT categories in South Carolina. As seen from the results in Table 3, the null hypothesis is rejected at the 5 percent level; therefore, the rate of change (before versus after) of accidents was significantly greater

Table 1. Number of all accidents and accidents at signalized intersections involving RT and NRT in South Carolina, 1976-1980.

Accident Type	1976	1977	1978	1979	1980	Average Change (%)[a]
All Accidents						
Property damage only	72,216	76,492	81,609	80,674	74,936	+0.93
Injury	14,020	14,175	15,486	15,952	15,328	2.25
Fatality	708	818	788	795	752	1.52
Total	86,944	91,485	97,883	97,394	91,016	1.15
Signalized Intersection NRT						
Property damage only	7,493	8,563	9,186	8,939	8,865	4.29
Injury	1,684	1,829	1,956	2,039	2,059	5.15
Fatality	24	29	20	23	24	0
Total	9,201	10,421	11,162	11,001	10,948	4.44
Signalized Intersection RT						
Property damage only	750	948	1,059	1,112	1,027	8.18
Injury	89	78	98	100	112	5.91
Fatality				2	1	
Total	839	1,026	1,157	1,214	1,140	7.97

[a]Calculated by using the geometric mean (see Equation 1).

Table 2. Number of all accidents and accidents at signalized intersections involving RT and NRT in Alabama, 1974-1981.

Accident Type	1974	1975	1976	1977	1978	1979	1980	1981	Average Change (%)[a]
All Accidents									
Property damage only	82,759	89,793	90,922	97,282	103,913	102,914	91,217	82,642	-0.020
Injury	17,264	18,663	19,506	21,112	23,352	23,270	21,904	21,113	2.92
Fatality	800	797	833	931	977	863	810	812	0.21
Total	100,823	109,253	111,261	119,325	128,242	127,047	113,931	104,567	0.52
Signalized Intersection NRT									
Property damage only	16,000	16,731	16,572	17,567	18,189	18,322	16,175	14,615	-1.29
Injury	2,840	3,109	3,236	3,392	3,616	3,686	3,384	3,368	2.47
Fatality	20	43	20	31	29	27	23	22	1.37
Total	18,860	19,883	19,828	20,990	21,834	22,035	19,582	18,005	-0.66
Signalized Intersection RT									
Property damage only	1,688	1,725	1,618	1,798	1,868	1,863	1,653	1,412	-2.52
Injury	117	111	129	149	137	144	125	112	-0.62
Fatality	0	0	0	2	1	1	1	0	
Total	1,805	1,836	1,747	1,948	2,006	2,008	1,779	1,525	-2.39

[a]Calculated by using the geometric mean.

Table 3. Chi-square test results for all NRT and RT accidents at signalized intersections before and after RTOR law in South Carolina.

Accident	Before	After	Total
RT	1,865	3,511	5,376
NRT	19,622	33,111	52,733
Total	21,487	36,622	58,109

Note: $\chi_0^2 = 13.283 > \chi^2(0.05, 1) = 3.84$ . . . Reject H_0: There is no significant difference in the change of accident frequencies at SIs for RT and NRT operations.

for RT than the corresponding change in NRT accidents at SIs for the time periods tested.

For Alabama, there were 8 years of data (1974-1981) and thus, on a quarterly basis, 32 data points were available to remove the effects of seasonality and trend from the data. The control group used to both estimate the seasonal factors and determine the slope of the trend line was all accidents in Alabama excluding all those at SIs. The estimates of seasonal factors for winter, spring, summer, and fall are, respectively, $Sn_1 = 0.94175$, $Sn_2 = 1.00220$, $Sn_3 = 0.99378$, 0.99378, and $Sn_4 = 1.06227$. These factors were computed by using the method of centered moving averages (5). The deseasonalized data for the control group were then used to obtain the trend line

$$d_t = 21{,}745.041 + 81.1405\ t,\quad t = 1, 2, 3, \ldots, 32$$

based on a quarterly average of 23,088.86 accidents. Because the quarterly average for all NRT (property damage plus injuries) was 5,032.66, the trend slope for NRT accidents is approximately

$$b_{11} = (5{,}032.66/23{,}088.86)\ (81.1405) = 17.69$$

Similarly, the trend slope for property damage only (PDO) and injuries (INJ) were computed, respectively, to be $b_{12} = 14.744$ and $b_{13} = 2.9463$. For RT accidents the trend slopes are $b_{21} = 1.61$, $b_{22} = 1.497$, and $b_{23} = 0.113$ for the categories of All, PDO, and INJ, respectively. These slopes were used to detrend the deseasonalized data. The deseasonalized quarterly data are given in Tables 4 and 5. Table 6 gives the statistics of NRT and RT accidents, where B refers to the time period before the RTOR law (1974-1976) and A refers to the time period after the RTOR law (1977-1981). The original observations were based on monthly data; therefore, the quarterly averages $\overline{X}_B$ contained 36 (12 x 3) monthly observations and $\overline{X}_A$s was based on 60 monthly averages. Therefore, by the central limit theorem, both $\overline{X}_B$ and $\overline{X}_A$ are approximately normally distributed. Furthermore, the standard errors of the means (s.e.) for before and after are obviously significantly different (except in the case of injuries), so that the t-test (called t' for unequal variances) was conducted (6). The results of the t'-test are summarized in Table 7, which gives in all three categories

$$t'\ (RT) < t'\ (NRT)$$

that is, the effect of the intervention (RTOR law) at a SI was relatively more significant for NRT than for RT accidents. Also, the only statistically significant difference was found in the case of NRT injury accidents. For the RT accidents, the quarterly average number of accidents decreased after the RTOR law for the All and PDO categories and slightly increased (but not significantly) for the INJ category. However, the increase in quarterly average NRT accidents for the INJ category cannot be attributed to the RTOR law because the NRT accidents had no vehicle turning right during the accident interval. Finally, the average number of accidents (after removing seasonality and trend) decreased (not statistically significant) after the RTOR law for the All and PDO categories but increased (not significantly) for the INJ category. Therefore, the law had no overall significant effect on average quarterly number of accidents in Alabama.

A χ^2 test (with r = 1 df) similar to Table 3, using the deseasonalized and detrended data, gave $\chi_0^2 = 0.901$ with the critical level $\hat{\alpha} = \Pr.\ (\chi_{r=1}^2 \geq 0.901) = 0.343$. Thus, the hypothesis of no difference in frequency of accidents at SIs for RT and NRT accidents before and after the intervention could not be rejected for Alabama. By using the raw data the value of χ_0^2 was computed to be 0.894 resulting in $\hat{\alpha} = 0.345$ (this is in direct contrast to South Carolina's $\chi_0^2 = 13.283$).

Severity

The analysis of the data in Tables 1 and 2 revealed that the greatest percentage of change in RT accidents in South Carolina was in the PDO category. The next step was to test the injury-fatality acci-

Table 4. Detrended and deseasonalized NRT data for Alabama.

Year	Quarter	Property Damage Only	Injury	All Accidents
1974	1	3950.2	703.1	4653.3
	2	2927.8	728.5	3656.3
	3	4148.9	705.6	4854.5
	4	3835.5	693.3	4528.8
1975	5	3905.0	696.7	4601.7
	6	3942.8	753.6	4696.4
	7	4322.3	836.7	5159.0
	8	4161.5	783.2	4944.7
1976	9	4166.7	795.4	4962.1
	10	4058.4	787.7	4846.1
	11	3800.4	728.3	4528.7
	12	3936.9	818.4	4755.3
1977	13	4104.5	734.7	4839.2
	14	3952.5	811.9	4764.4
	15	4274.8	829.2	5104.0
	16	4362.7	867.9	5230.6
1978	17	4179.4	750.5	4929.9
	18	4324.6	883.9	5208.5
	19	4342.7	869.8	5212.5
	20	4245.3	912.6	5157.9
1979	21	4513.3	858.7	5372.0
	22	4082.0	867.2	4949.2
	23	4291.7	846.9	5138.6
	24	4128.9	873.5	5002.4
1980	25	4140.0	838.4	4978.4
	26	3620.9	720.7	4341.6
	27	3439.8	773.7	4213.5
	28	3448.7	765.7	4214.4
1981	29	3367.4	799.1	4166.5
	30	3026.1	719.8	3745.9
	31	3229.8	731.8	3961.6
	32	3200.5	780.2	3980.7

Note: $tr_t = d_t = 4740.78 + 17.69\ t$ for all accidents.

Table 5. Detrended and deseasonalized quarterly RT data for Alabama.

Year	Quarter	Property Damage Only	Injury	All Accidents
1974	1	396.7	32.8	429.5
	2	390.1	33.7	423.8
	3	446.3	21.8	468.1
	4	437.4	27.7	465.1
1975	5	425.7	22.8	448.5
	6	409.1	34.2	443.3
	7	404.1	27.4	431.5
	8	445.5	23.6	469.1
1976	9	420.8	26.6	447.4
	10	366.2	43.8	410.0
	11	389.0	30.0	419.0
	12	381.1	24.0	405.1
1977	13	427.5	28.2	455.7
	14	433.0	49.3	482.3
	15	414.2	39.6	453.8
	16	435.4	27.4	462.8
1978	17	397.2	26.8	424.0
	18	412.1	45.9	458.0
	19	470.7	18.0	488.7
	20	472.8	38.2	511.0
1979	21	478.3	45.4	523.7
	22	403.1	26.4	429.5
	23	438.5	29.6	468.1
	24	412.2	34.0	446.2
1980	25	439.4	21.6	461.0
	26	376.2	30.0	406.2
	27	324.9	30.1	355.0
	28	358.2	31.6	389.8
1981	29	327.2	28.6	355.8
	30	294.4	24.5	318.9
	31	306.8	20.7	327.5
	32	302.3	24.6	326.9

Note: $tr_t = d_t = 431.42 + 1.61\ t$ for all accidents, $t = 1,2, \ldots 32$.

Table 6. Quarterly statistics before and after RTOR law for RT and NRT in Alabama.

Category	Accident Type	1974-1976 Quarterly $\bar{X}_B$	s.e. of $\bar{X}_B$	1977-1981 Quarterly $\bar{X}_A$	s.e. of $\bar{X}_A$
NRT	All	4765.58[a]	55.62[a]	4725.60	114.39
	PDO	4013.04	45.41	3913.74	104.14
	Injury	752.54	14.53	811.81	13.65
RT	All	438.40	6.38	427.25	13.95
	PDO	409.33	7.53	396.22	13.12
	Injury	29.03	1.82	31.03	1.93

[a] $\bar{X}_B = (4653.3 + 4656.3 + \ldots + 4755.3)/12 = 4765.58$

$\hat{\sigma}_B = \left[\sum_{i=1}^{12} (X_i - 4765.58)/11\right]^{1/2} = 192.680$

where $X_i = 4653.3,\ X_2 = 4656.3, \ldots, X_{12} = 4755.3$.

$Se(\bar{X}_B) = \hat{\sigma}_B/\sqrt{12} = 55.622$.

Table 7. Results of t-test for NRT and RT accidents in Alabama.

Statistic	NRT Accidents All	NRT Accidents PDO	NRT Accidents Injury	RT Accidents All	RT Accidents PDO	RT Accidents Injury
t'-test	-0.3144[a]	0.874	2.973	-0.727	-0.867	0.754
Degrees of freedom	27.5[b]	26	29	26.7	29.6	31
Critical level, $\hat{\alpha}$, for two-sided test	0.767[c]	0.391	0.0059	0.474	0.393	0.46

[a] $t' = (\bar{X}_A - \bar{X}_B)/\sqrt{Se^2(\bar{X}_A) + Se^2(\bar{X}_B)} = (4725.60 - 4765.58)/\sqrt{114.39^2 + 55.62^2} = -0.31432$.

[b] $\nu = [Se^2(\bar{X}_A) + Se^2(\bar{X}_B)]^2/\{[Se^4(\bar{X}_A)/n_A + 1] + [Se^4(\bar{X}_B)/n_B + 1]\} - 2 = (114.39^2 + 55.62^2)^2/[(114.39^4/21) + (55.62^4/13)] - 2 = 29.445 - 2 = 27.5$.

[c] $\hat{\alpha} = Pr \cdot (t_{\nu=27.5} \geq 0.3144) = 0.767$.

dents for RT and NRT operations. The null hypothesis tested was that no difference exists in the frequency of RT and NRT injury-fatality accidents before and after the effective date of South Carolina's RTOR law. The results in Table 8 show that the null hypothesis could not be rejected at a significant level as large as 37 percent ($\hat{\alpha} = 0.37$). Therefore, we conclude that there is no significant difference between NRT and RT injury-fatality accidents at SIs for the time periods tested. A similar χ^2 test for Alabama gave $\hat{\alpha} = 0.104$. However, such a small critical level was mostly caused by the significantly larger average number of accidents per year for the after period than the average during

Table 8. Chi-square test results for NRT and RT injury-fatality accidents at signalized intersections before and after RTOR law in South Carolina and Alabama.

Accident	Before	After	Total
South Carolina[a]			
RT observed	167	313	480
NRT observed	3,566	6,121	9,687
Total	3,733	6,434	10,167
Alabama[b]			
RT observed	384.4	620.50	1,004.9
NRT observed	9,030.50	16,236.20	25,266.7
Total	9,414.90	16,856.70	26,271.60

[a] $\chi_0^2 = 0.894 < \chi^2(0.05; 1) = 3.84$. Cannot reject H_0: There is no difference in the change (from before to after) of accident frequencies at SIs for RT and NRT operations in South Carolina.

[b] $\chi_0^2 = 2.652 < \chi^2(0.05; 1) = 3.842$. Cannot reject H_0: There is no difference in the change (from before to after) of accident frequencies at SIs for RT and NRT operations in Alabama, at the 5 percent level of significance.

Table 9. Chi-square test results for NRT and RT property-damage-only accidents at signalized intersections before and after RTOR law in South Carolina and Alabama.

Accident	Before	After	Total
South Carolina[a]			
NRT observed	16,056	26,990	43,046
RT observed	1,698	3,198	4,896
Total	17,754	30,188	47,942
Alabama[b]			
NRT observed	48,156.4	78,274.7	126,431.1
RT observed	4,912.0	7,924.4	12,836.4
Total	53,068.4	86,199.1	139,267.5

[a] $\chi_0^2 = 12.924 > \chi^2(0.05; 1) = 3.84, \ldots$ Reject H_0: There is no difference in the change (from before to after) of property damage accidents at SIs for RT and NRT operations in South Carolina.

[b] $\chi_0^2 = 0.155 < \chi^2(0.05; 1)$. Cannot reject H_0: There is no difference in the change (from before to after) of property damage accidents at SIs for RT and NRT accidents in Alabama.

Table 10. Percentage of NRT and RT property-damage-only accidents by estimated cost of total property damage for South Carolina.

	1976		1977		1978		1979		1980	
Cost	RT	NRT	RT	NRT	RT	NRT	RT	NRT	RT	NRT
Less than $200	19.9	14.5	21.3	15.9	21.7	15.1	16.5	11.7	14.6	11.0
$200-$499	46.2	33.5	42.1	28.8	39.6	26.0	39.1	24.8	36.2	21.9
$500-$999	23.0	25.1	24.0	25.4	24.8	25.3	25.0	26.1	25.3	24.8
$1000-$1499	5.5	12.4	6.6	13.4	7.7	14.2	9.9	14.6	10.8	15.7
$1500-$1999	2.5	5.5	2.9	6.4	2.8	7.2	3.9	7.3	6.1	8.0
$2000-$2499	0.9	3.1	1.2	3.7	1.1	4.3	1.9	5.3	3.2	5.9
More than $2500	2.1	6.0	1.9	6.3	2.3	7.9	3.6	10.3	3.8	12.6

Table 11. Percentage of NRT and RT property-damage-only accidents by estimated cost for total property damage for Alabama.

	1974		1975		1976		1977		1978		1979		1980		1981	
Cost	RT	NRT	RT	NRT	RT	NRT	RT	NRT	RT	NRT	RT	NRT	RT	NRT	RT	NRT
Less than $600	84.8	69.85	81.7	65.8	79.8	61.7	74.5	57.9	70.7	55.4	68.8	50.2	64.2	47.4	60.6	45.5
$601-$1200	10.8	18.9	13.3	20.6	14.1	21.8	17.1	22.6	18.9	22.4	20.5	23.2	22.1	23.1	22.4	22.1
$1201-$2000	3.6	8.1	4.0	9.7	4.5	11.2	6.3	12.5	7.3	13.6	7.1	15.6	8.7	16.3	10.4	17.3
$2001-$3000	0.5	1.9	0.6	2.3	1.0	3.0	1.3	4.1	1.7	4.6	2.0	5.5	2.9	6.1	3.5	6.6
$3001-$4000	0.2	0.9	0.3	1.0	0.3	1.4	0.4	1.8	0.8	2.4	1.0	3.1	1.5	3.8	1.8	4.4
$4001-$5000	0	0.3	0.1	0.3	0.2	0.4	0.2	0.5	0.2	0.6	0.3	1.0	0.3	1.2	0.5	1.6
$5001-$6000	0.2	0.2	0.1	0.2	0.1	0.3	0.2	0.4	0.2	0.6	0.2	0.8	0.4	1.1	0.6	1.2
$6001-$8000	0	0	0.1	0.1	0.1	0.2	0.1	0.2	0	0.3	0	0.4	0.2	0.6	0.4	0.8
More than $8000	0.1	0	0	0.1	0.1	0.2	0.1	0.2	0.2	0.3	0.2	0.5	0	0.6	0	0.7

the before period in the NRT group, but this was not so for the RT group.

The results of the analysis of accident trends revealed that in South Carolina there was a significant difference between all RT and NRT accidents but no significant differences were found between RT and NRT injury-fatality accidents before and after RTOR law. The next step was to examine the severity of RT and NRT accidents at SIs. By using the null hypothesis that there is no difference between property damage accidents at SIs for RT and NRT accidents before and after the effective date of South Carolina's RTOR law, the data in Table 9 were tested for significance by using the χ^2 test. The null hypothesis is rejected at the 5 percent level. From Tables 1 and 2, the average change in percent for RT property damage accidents was approximately twice the average change for NRT property damage accidents for the 1976-1980 period in South Carolina. Thus, we conclude that PDO accidents for RT increased at a significantly faster rate than property damage accidents for NRT operations at SIs. However, a similar χ^2 test (using the deseasonalized data) for Alabama gave $\chi_0^2 = 0.155$ for which $\hat{\alpha} = 0.694$ (i.e., for PDO accidents no significant difference between the change from before the law to after in RT and NRT operations was found).

The percentage of property damage accidents in South Carolina for RT and NRT operations is shown in Tables 10 and 11 for selected ranges of property damage costs. Property damage costs included the estimated cost of all vehicular damage and property damage costs. In Tables 10 and 11 the estimated property damage costs for RT accidents were much lower than the equivalent costs for NRT accidents. For example, an average of 84 percent of the RT accidents in South Carolina resulted in property damages less than $1,000 as compared with only 69 percent of the NRT accidents. In Alabama an average of 90.5 percent of RT accidents had property damage cost less than $1,200; however, this figure for the NRT accidents was 78.5 percent.

The percentage of NRT accidents that resulted in an injury-fatality was about twice the percentage of RT accidents that resulted in an injury-fatality. By using data from Tables 1 and 2, 18.2 percent (15.9

Table 12. Total victims and pedestrian victims of RT and NRT accidents at signalized intersections in South Carolina and Alabama.

		RT Accidents			NRT Accidents		
State	Year	Pedestrians	Total Victims	Percentage Pedestrians	Pedestrians	Total Victims	Percentage Pedestrians
South Carolina	1976	19	112	17	119	2,267	4.5
	1977	21	99	21.2	130	2,914	4.5
	1978	25	125	20	150	3,015	4.9
	1979	34	143	23.8	144	3,101	4.6
	1980	33	140	23.5	169	3,126	5.4
Total		132	619	21.3	712	17,859	4.8
Alabama	1974	22	117	18.8	147	2,860	5.1
	1975	17	111	15.3	137	3,152	4.3
	1976	15	129	11.6	138	3,256	4.2
	1977	24	151	15.9	131	3,423	3.8
	1978	15	138	10.9	127	3,645	3.5
	1979	23	145	15.9	122	3,713	3.3
	1980	11	126	8.7	129	3,407	3.8
	1981	14	112	12.5	126	3,390	3.7
Total		141	1,029	13.7	1,057	26,846	3.9

Table 13. Chi-square test results for NRT and RT pedestrian accidents at signalized intersections before and after RTOR law in South Carolina and Alabama.

State	Before	After	Total
South Carolina[a]			
NRT observed	249	463	712
RT observed	40	92	132
Total	289	555	844
Alabama[b]			
NRT observed	422	635	1,057
RT observed	54	87	141
Total	476	722	1,198

[a] $\chi_0^2 = 1.01 < \chi^2\ (0.05; 1) = 3.84$. Cannot reject H_0.
[b] $\chi_0^2 = 0.1374 < \chi^2\ (0.05; 1)$. Cannot reject H_0: There is no significant difference in the change (from before to after) of pedestrian accident frequencies at SIs for NRT and RT categories in Alabama.

percent in Alabama) of all NRT accidents for the before and 18.2 percent (17.2 percent in Alabama) in the after period resulted in an injury-fatality as compared with 8.95 percent (6.63 percent in Alabama) for before and 8.4 percent (7.25 percent in Alabama) in the after period for RT accidents. Thus, the proportion of injury-fatality accidents to all accidents has not changed significantly during the 5-year period in South Carolina or the 8-year period in Alabama. During these periods there have only been three fatal RT accidents in South Carolina and only five in Alabama.

Some of the important findings in this section are as follows:

1. The increase (from before to after) of RT PDO accidents was significantly greater than the corresponding increase in the NRT category. For Alabama the decrease (from before to after) of RT PDO accidents was not significantly lower than the decrease in NRT accidents.
2. The average property damage costs for RT accidents was much lower than the average property damage costs for NRT accidents in both states.
3. RT injury-fatality accidents as a percentage of total accidents at SIs did not increase significantly for the after period. NRT injury-fatality accidents as a percentage of total accidents at SIs remained practically unchanged from the before to the after period.

Pedestrian Involvement

Pedestrian safety at RTOR intersections is of major concern. Wide ranges of pedestrian involvement in RTOR accidents have been reported. McGee (7) reported that the percentage of RTOR accidents involving pedestrians varied from 0 to 33 percent. Zador and others (2) reported that pedestrian crashes increase substantially as a result of RTOR. Certainly, the RT operation at a SI represents a potential vehicular-pedestrian conflict regardless of whether the vehicle is turning right on a red or a green signal phase.

Pedestrain involvement in South Carolina accidents at SIs for RT and NRT operations is given in Table 12. For South Carolina accidents involving RT, approximately 1 out of every 5 victims was a pedestrian (1 in 7 for Alabama) whereas the ratio was approximately 1 out of every 21 for NRT accidents (1 in 25 for Alabama). These results confirm the high involvement of pedestrians as victims in RT accidents.

To determine if pedestrian involvement in RT accidents has increased as a result of RTOR law, the null hypothesis that no difference exists between pedestrian involvement in RT and NRT accidents before and after the effective date of the RTOR law was tested. The χ^2 test in Table 13 was used to show that the null hypothesis cannot be rejected for either South Carolina or Alabama (the respective critical levels are 0.299 and 0.711). Thus, we conclude that there is no statistically significant difference between RT and NRT pedestrian accidents before and after RTOR. There is no reason to suspect that pedestrian accidents involving RT operations have increased after the adoption of RTOR in either state.

Some of the important findings in this section are as follows.

1. Approximately 1 out of every 5 victims of a RT accident was a pedestrian in South Carolina (1 in 7 for Alabama) whereas only 1 out of every 21 (1 in 25 for Alabama) victims was a pedestrian in NRT accidents at signalized intersections.
2. The difference was not significant between pedestrian accidents involving RT and NRT operations before and after the effective date of the RTOR law in both states. Therefore, we conclude that no statistically significant increase in pedestrian accidents has resulted from the RTOR laws.
3. In South Carolina the percentage of pedestrian involvement remained constant for both RT and NRT categories; however, in Alabama the percentage

Table 14. Percentage of accidents at signalized intersections by RT and NRT categories.

Year	NRT (%) S.C.	NRT (%) Ala.	RT (%) S.C.	RT (%) Ala.	Percentage of Total Accidents that Occurred at Traffic Signal S.C.	Percentage of Total Accidents that Occurred at Traffic Signal Ala.
1974		91.27		8.73		20.50
1975		91.55		8.45		19.88
1976	91.64	91.90	8.36	8.10	11.55	19.39
1977	91.04	91.50	8.96	8.50	12.55	19.22
1978	90.61	91.59	9.39	8.41	12.59	18.59
1979	90.06	91.65	9.94	8.35	12.54	18.92
1980	90.54	91.67	9.46	8.33	13.24	18.75
1981		92.20		7.80		18.68

of pedestrian involvement showed a slight declining trend.

RTOR AND PUBLIC GOOD

Reported estimates of decreases in fuel consumption and travel time that result from RTOR operations vary widely according to the assumptions made by the investigators or because of the environmental conditions under which the study was conducted. Chang and others (8) reported a 6 percent decrease in fuel consumption and a 12 percent decrease in travel time after the introduction of RTOR in downtown Detroit. Lieberman (9) made a comparison of a signal system with and without RTOR. His results indicated a 4 percent decrease in fuel consumption and a 6 percent reduction in emissions. Obviously the number of SIs with RTOR and the number of vehicles that execute the RTOR maneuver are the primary factors in estimating the savings in fuel and travel time. South Carolina has approximately 1,800 SIs; about 90 percent (1,620) of these permit RTOR. In 1980 there were 2.07 million registered vehicles and 1.95 million licensed drivers in South Carolina, which generated 22.66 billion vehicle miles of travel (10). About 30 percent of the vehicle miles of travel was urban. One source (2) estimated that RTOR operations would produce an annual savings of up to 1.3 gal of fuel/registered vehicle. For South Carolina, using this value, the savings in fuel is estimated to be approximately 2.7 million gal/year. Another benefit would be the reductions in vehicle emissions that would be realized from RTOR operations. For each 650 gal of fuel consumption by an idling engine, emissions consist of 2,430 lb of carbon monoxide, 160 lb of hydrocarbons, and 50 lb of nitrogen oxides (11). Based on the estimated annual fuel savings of 2.7 million gal, the following reductions in emissions would be realized:

1. Carbon monoxide--5,047 tons,
2. Hydrocarbons--332 tons, and
3. Nitrogen oxides--104 tons.

In addition to the estimated savings in fuel and reductions in vehicle emissions, time savings are available to drivers because of reduced stopped delay at traffic signals. For progressive signal systems, the RTOR operation enables the vehicle turning right to join the progressive movement on the other street because it would be passing through the intersection during a green phase (i.e., turning right on red), thus further reducing stopped delays. The estimated range of time saved by the driver varies from 0.3 to 1.7 hours per driver per year (2). For South Carolina drivers the estimated time saved would range from 0.6 to 3.3 million hours. The preceding analysis could be repeated for Alabama. In 1980 Alabama had approximately 2.5 million licensed drivers, and approximately 26.01 billion vehicle miles were driven in this state. Since Alabama has approximately the same rural-urban mix, a factor of 1.2 may be applied to the above figures to generate comparable Alabama information.

Costs are usually associated with benefits. For RTOR operations these costs would result from an increase in RTOR accidents. Table 14 gives the percentage of accidents at SIs, computed using the totals in Tables 1 and 2 for NRT and RT categories. For example, the percentage for 1976 under the RT category in South Carolina is simply:

$$[839/(839 + 9201)]\ 100 = 8.36 \text{ percent}$$

The last column in Table 14 gives the percentage of total accidents that occurred at SIs. From the data shown, the increase in South Carolina in RT accidents has been very small and is estimated at approximately 1 percent due to RTOR. There was a decrease of about 0.15 percent in this measurement for Alabama. We may calculate that the percentage of accidents that occur at SIs is (52,733 + 5,376/464,722) x 100 = 12.5 percent of the total reported accidents in South Carolina (19.21 percent for Alabama). Thus, the annual increase in accidents in South Carolina that result from RTOR operations based on a 5-year average is approximately 116 accidents (0.01 x 0.125 x 92,944). Most of this increase was in property damage (Table 1).

Some of the important findings in this section are as follows:

1. The estimated annual fuel savings in South Carolina that resulted from reduced stopped delays due to RTOR is 2.7 million gal (3.24 million gal for Alabama) based on a savings of 1.3 gal/registered vehicle.
2. The estimated annual reduction in vehicle emissions resulting from reduced stopped delays due to RTOR is as follows (a) carbon monoxide--5,047 tons for South Carolina and 6,056 for Alabama, (b) hydrocarbons--332 tons for South Carolina and 398.4 for Alabama, and (c) nitrogen oxides--104 tons for South Carolina and 124.8 for Alabama.
3. The estimated annual time savings by drivers resulting from reduced stopped delays due to RTOR varies from 0.6 million hr to 3.3 million hr based on a savings of 0.3 to 1.7 hr/year/driver.
4. The increase in RT accidents attributed to RTOR operatons was about 1 (-0.15 for Alabama) percent of the total accidents occurring at signalized intersections. About 12.5 (19.21 in Alabama) percent of the total reported accidents in South Carolina occur at signalized intersections.
5. The increase in annual accidents in South Carolina attributable to RTOR operations is about 116 accidents, consisting mostly of rear-end PDO accidents. However, in Alabama the number of accidents due to RTOR decreased at an annual rate of about 33.

CONCLUSIONS AND RECOMMENDATION

South Carolina's RTOR law, which permits RTOR except at locations where it is specifically prohibited by traffic signs, was passed into law on February 15, 1977, and the law became effective on May 16, 1977. Before the passage of this law South Carolina prohibited RTOR except at locations where it was permitted by traffic signs. A similar set of circumstances also transpired in Alabama, which passed its RTOR law, effective immediately, on August 18, 1976. The most significant difference in the average percentage of change between RT and NRT accidents was in the higher rate of change in PDO accidents for RT operations. A slight increase was measured in South Carolina, but in Alabama there was a corresponding reduction. The average rate of change for injury accidents was about the same for both RT and NRT accidents in both states. RT accidents tend to be less severe and have lower property damage costs when compared with all signalized intersection accidents. As a result of several statistical tests, we concluded that there was no significant difference in pedestrian involvement in RT accidents before and after the effective date of the RTOR law compared with all pedestrian accidents at signalized intersections.

Approximately 116 accidents/year can be attributed to South Carolina's RTOR operations and no significant increases were found in Alabama. An analysis of the data indicated that most of the increase in RT accidents was in the category of property-damage-only and involved rear-end collisions.

Numerous economic benefits result from RTOR operations, including savings in fuel consumption, reduced vehicle emissions, and time savings to the drivers. For the two states these benefits are summarized as follows:

1. Fuel savings--59.4 million gal/year;
2. Reduction in vehicle emissions per year--(a) carbon monoxide--11,103 tons, (b) hydrocarbons--730.4 tons, and (c) nitrogen oxides--229 tons; and
3. Times savings per year--1.3 to 7 million hr.

Based on the findings of this study, no changes are warranted in South Carolina's or Alabama's RTOR law and these laws should remain in effect.

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