REFLECTORIZED LICENSE PLATES: DO THEY REDUCE NIGHT REAR-END COLLISIONS?

Charles B. Stoke, Virginia Highway Research Council

In Virginia 100,000 sets of experimental reflectorized and 100,000 sets of control nonreflective 1971 license plates were randomly distributed. Each distribution point in the state received and sold a pro rata number of each type. Plates were distributed evenly throughout each day of the distribution period. Accident data for the vehicles using experimental and control plates were collected for a 12-month period. These data were specifically coded and stored for retrieval by the state police. The reporting format distinguished between the striking vehicle and the vehicle struck. Reflectorized and control comparisons involved statewide data concerning night and daytime accidents. The age of the driver, his or her driving experience, the age of the vehicle, and the weather conditions at the time of the crash were analyzed; accident data were also analyzed. There was no statistically significant difference between the number of night rear-end collisions and crashes of vehicles equipped with reflectorized license plates and those with control nonreflective license plates.

•MANUFACTURERS, researchers, and highway safety enthusiasts, in the United States and abroad, have been interested in reflectorized license plates since at least 1950. The Virginia Highway Research Council has conducted studies on their use. One of these studies, by Stoke and Simpson (1), dealt with legibility and visibility. Field experiments were carried out on an unopened section of Interstate highway, and the plates were attached to the rear of an automobile. The results were similar to those from previous studies (2, 3, 4).

Legislation on reflectorized license plates has been introduced on several occasions in the Virginia General Assembly. The issuance of experimental reflectorized plates was authorized in Va. Code Ann. Sec. 46.1-103.1 (1970). Under this statute 100,000 sets of reflectorized plates and 100,000 sets of control nonreflective plates were issued for research purposes. All plates had black numbers on a white background.

The main question to be answered before adopting the use of reflectorized license plates is whether they provide greater safety by decreasing night rear-end collisions. Several studies have purportedly demonstrated crash reductions attributable to reflectorized plates. A 1959 study (5) conducted in Polk County, Iowa, divided resident vehicle owners into 2 groups: 1 group (60.1 percent of the total) was provided reflectorized plates and the other group (39.9 percent of the total) was given regular steel and enamel plates. The study found that the distributions of night rear-end collisions involving parked cars differed markedly between the 2 groups of plates; 76.7 percent of the struck cars did not have reflectorized plates. But, the Polk County study was deficient in its sampling design because the experimental plates were put on sale first and sold until the supply was exhausted. The possibility exists that persons who purchased their plates early differed in social, psychological, and other demographic characteristics from the later group of purchasers. And, this study did not take into account the number of accidents that occurred in daylight hours or vehicle conditions

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other than parked. It also did not determine whether the accident differences between the 2 groups were statistically significant.

Reflectorized plates were adopted in North Carolina in 1967 with the requirement that they be evaluated for their crash reduction effectiveness. A study on the safety benefits of reflectorized plates was conducted by the Highway Safety Research Center of the University of North Carolina. Researchers studied the occurrences of rear-end collisions for cars with reflectorized plates and those having nonreflective plates during a 6-week grace period when old plates were being replaced. This approach avoided the difficulties of before and after studies, but the design was suspect because a distribution method similar to that of the Polk County study was used and because persons purchasing plates early might have differed in some characteristics from those purchasing late. The authors state, "Circumstances of sample size and unavoidable limitations of study design preclude assertion that the effectiveness of reflectorized plates has been proved in an absolute sense" (6).

METHODOLOGY

The Virginia study followed a specific method for the distribution of control and experimental license plates for 1971. Data collection and analyses also followed a predetermined format.

Distribution of Plates

Random distribution of the license plates is important to ensure that the experimental group differed in only 1 measurable respect—reflectorization—from the control group. Random assignment samples the general population. Prior random selection permits the application of statistical logic to assess obtained differences on the experimental variables (rear-end and parked collisions at night) after use of reflectorized plates. A failure to randomize opens the possibility that the experimental and control groups do not represent the same driving population.

The method used by Virginia to distribute 100,000 sets of reflectorized and 100,000 sets of control group 1971 license plates lent itself to statistical analysis. The numbers of reflectorized and control plates sold at each of the distribution points throughout the state in 1971 were prorated for each distribution point by the percentage of plates sold in 1970. For example, a distribution point which had issued 5 percent of the total passenger car license plates during the preceding renewal period received 5 percent of both reflectorized and control plates. During the distribution period from March 15 to April 15 reflectorized and control license plates were sold on a prearranged basis. Neither type was available on request by the purchaser. Equal numbers of both types were sold each day of the renewal period. This method was used to ensure geographical coverage of the entire state, to prevent all the experimental plates from being sold at once, and to ensure everyone an equal opportunity to obtain such plates.

Data Collection

It was necessary to compare the 1971 accident data of the group that used reflectorized plates with those of the group that used control nonreflective plates on their vehicles to determine whether there was a safety advantage to using reflectorized plates. Rear-end and parked collisions were considered for the safety benefit analysis, because it is in the reduction of these types of accidents that reflectorized license plates are supposed to have their most important benefits.

In determining collision reduction, multivehicle crashes were considered and the reporting scheme distinguished between the striking vehicle and the vehicle struck. Data on the age and experience of the driver, the age of the motor vehicle, weather conditions, and accident data were obtained for both urban and rural locations and were analyzed to determine what role they played in accidents.

The state police furnished computer tapes of accident records to the Virginia Highway Research Council. Enough time was allowed for complete reporting of accidents by individuals and investigating officers and for the processing of the information from the accident report forms by the Division of Motor Vehicles and the state police.

Control and experimental group accident data were obtained to determine whether a safety advantage resulted from the use of reflectorized automobile license plates during nighttime (6:00 p.m. to 6:00 a.m. from October through March, and 9:00 p.m. to 6:00 a.m. from April through September).

Collision data were obtained from 9 state police accident report categories (8). The categories and conditions were as follows for intersection rear-end collisions with both vehicles in the same direction:

1. Both going straight;
2. One turning right, the other going straight;
3. One turning left, the other going straight;
4. One stopped; and
5. All others.

The categories and conditions were as follows for nonintersection rear-end collisions with both vehicles in the same direction:

1. Both going straight;
2. One vehicle parked properly;
3. One vehicle parked improperly; and
4. One vehicle stopped in traffic.

Data Analyses

Were the reflectorized and control license plate samples comparable groups? Although considerable effort was expended to randomly distribute the plates and thereby have similar groups, the data were tested to determine whether in fact the groups were similar. Statistical tests were applied to the following categories of daytime accidents where crash is any reportable traffic accident and collision is a crash involving 2 or more motor vehicles: crashes by type, collisions by type, age and experience of the drivers involved in the accidents, age of the vehicles involved, and weather conditions when the accidents occurred. Also used were night crashes and collisions (excluding the experimental variables) by type. Data for these analyses were obtained from the state police.

The 50 percent probability test, an extended version of the binomial test for cases in which the known or expected average is 50 percent, is used to compare any 2 things expected to differ from each other only by chance. The test is designed to compare 2 isolated occurrences, such as accidents, if the expected number of occurrences in each sample is the same, such as when both samples have the same duration and are drawn from parent groups of the same size. This test was used to determine whether differences in the number of rear-end collisions of passenger cars with reflectorized license plates and those with control nonreflective license plates occurred by chance.

The conventional way of comparing 2 samples of isolated occurrences is to use the 2-cell chi-square (X^2) test with Yates' correction for continuity, but the 50 percent probability test gives identical answers with large samples and more accurate answers with small samples (7). The data required for the 50 percent probability test are

x = number of occurrences in smaller sample,
y = number of occurrences in larger sample, and
$x + y$ = number of occurrences in both samples.

To calculate the value X^2, the following formula was used:

$$X^2 = \frac{(|x - y| - 1)^2}{x + y}$$

The critical values of X^2 for this test are 3.84 for P.E. < 0.05 and 6.63 for P.E. < 0.01.

If the control license group is not statistically different from the reflectorized license group, we can proceed with the test.

Were there significantly fewer night collisions for vehicles with experimental license plates than for vehicles with control plates? To resolve this question, night data comparisons by collision type, directional analysis, fatal accidents, personal injury accidents (PI), property damage accidents (PD), weather conditions (WC), driver experience (DX), driver age (DA), and vehicle age (VA) were used. The analyses followed this schematic format in making statistical comparisons:

Crashes → Collisions → Rear-End Collisions → 1. Directional Analysis
→ 2. Fatal, PI, PD
→ 3. WC, DX, DA, VA

The standard chi-square test for distribution of data and the 50 percent probability test for sets of data were used to determine whether the collision distributions and individual data sets of the 2 groups differ significantly for accident occurrence or whether the differences could be ascribed to chance. The data for these analyses were furnished by the Virginia state police and contained crash facts for the 1971 license plate year rather than for the 1971 calendar year and were specially developed for this study.

RESULTS OF ANALYSES

Analyses of the data occurred in 2 stages. First, it was necessary to determine whether the 2 study groups had similar accident experience when reflectorization was not an influencing factor. Then, if the groups were similar, it was necessary to determine the night rear-end and parked collision experience of the 2 groups.

Are the Experimental and Control Groups Comparable?

In determining the comparability of the 2 study groups, factors representing the influence of the vehicle, the roadway, and the driver on crashes were analyzed. In addition, comparisons were carried out for daytime crashes and collisions and for night crashes and collisions (excluding the experimental variables).

The data given in Tables 1 and 2 include every accident-involved vehicle from the 2 study samples. The data presented in the remainder of this section include only the vehicles involved in the primary collision. The inclusion of all crashes more adequately represents the true picture of vehicle crash involvement. Primary rear-end and parked car collision controls were used for those factors where neither plate type nor other driver, vehicle, or roadway characteristics influence vehicle collision involvement.

Table 1 gives a statistical comparison of daytime and night crashes. The number and distribution of daytime crashes of vehicles equipped with reflectorized license plates were not different from those of vehicles equipped with control nonreflective license plates. In night crashes, these 2 groups (minus rear-end and parked car crashes) also were not statistically different.

Table 2 gives data on the comparisons of daytime and night collisions. The reflectorized and the control license plate groups (again, minus the rear-end and parked car variables for night collisions) did not have a statistically different experience for the total number and distribution of these collisions.

Table 3 gives a summary of chi-square values obtained when the test was applied to the daytime rear-end categories of data. The distribution of daytime rear-end collisions of vehicles equipped with reflectorized plates as influenced by weather, driver, and vehicle variables was not different from the distribution of daytime rear-end collisions of vehicles equipped with control nonreflective license plates. In only 1 category—intersection collisions by vehicle age—were the differences more than chance expectations.

Table 4 gives a summary of the 50 percent probability test results given in Table 5. These are comparisons of individual data sets within each of the distributions of daytime rear-end collisions. Of the total data sets analyzed, 98 daytime sets were not significantly different and 7 daytime sets were significantly different—2 at the 0.01 level and 5 at the 0.05 level. Most were in the vehicle age category. Collision frequency for the 100,000 vehicles with control nonreflective license plates was not different from the collision frequency for the 100,000 vehicles with reflectorized license

Table 1. Comparisons by crash type.

Type	Daytime[a]		Night[b]	
	Reflectorized	Control	Reflectorized	Control
With another motor vehicle[c]	5,447	5,401	864	881
Other noncollision	13	16	7	5
With fixed object	80	70	68	75
Overturned in roadway	14	16	16	24
Ran off roadway	464	478	521	473
All other and not stated	124	122	101	83
Total	6,142	6,103	1,577	1,541

[a]Chi-square = 1.727 (not significant at the 0.05 level).
[b]Chi-square = 6.106 (not significant at the 0.05 level).
[c]Rear-end and parked car crashes are not included in the night comparison.

Table 2. Comparisons by collision type.

Type	Daytime[a]		Night[b]	
	Reflectorized	Control	Reflectorized	Control
Sideswipe	1,620	1,616	392	411
Head-on	591	617	249	245
Rear-end	1,620	1,510	—	—
Parked	645	645	—	—
Not stated and all others	971	1,013	223	225
Total	5,447	5,401	864	881

[a]Chi-square = 5.113 (not significant at the 0.05 level).
[b]Chi-square = 0.337 (not significant at the 0.05 level).

Table 3. Chi-square values of daytime collisions.

Category	Intersection		Nonintersection		Total	
	Chi-Square	Degrees of Freedom	Chi-Square	Degrees of Freedom	Chi-Square	Degrees of Freedom
Weather	5.634	5	3.206	5	7.406	6
Driver experience	1.406	4	5.770	4	2.792	4
Driver age	2.561	9	6.447	8	0.729	9
Vehicle age	17.545[a]	8	14.854	8	9.896	8

[a]Significant at 0.05 level.

Table 4. Summary of 50 percent probability test results for daytime rear-end collisions.

Category	Statistically Different	Not Statistically Different	Total
Weather	2	25	27
Driving experience	1	17	18
Age of driver	0	33	33
Age of vehicle	4	23	27

plates when weather, driver, and vehicle variables were considered.

The overwhelming similarity of these data led to the conclusion that the 2 groups were similar. Having determined this, one could determine whether reflectorization reduced night rear-end collisions.

Are Night Rear-End Collision Results Comparable?

Table 6 gives the 50 percent probability test results for total night rear-end collisions by accident type. Fatal, personal injury, property damage, and total accidents are shown for both study groups. Also included is a calculated number of control nonreflective collisions necessary for statistical significance at the 0.05 level when the number of reflectorized collisions is held constant. Although there were numerical differences between the 2 study groups, these differences were not greater than would be expected because of chance. Therefore, for these categories of night rear-end collisions, it was concluded that automobiles with reflectorized license plates did not have a significantly different collision experience when compared with automobiles with control nonreflective license plates.

Figure 1 shows 50 percent probability test values by accident type. Table 7 gives 50 percent test values for directional analysis. In every night category, there was no statistical difference between the group equipped with reflective license plates and the group equipped with control nonreflective license plates.

For night comparisons by collision type, the data category for parked cars is especially noteworthy because it is the one where the struck vehicle is usually unlighted. Differences for each data set and the distribution of collisions were not greater than could be expected because of chance. Automobiles with reflectorized and control nonreflective license plates did not have a different collision experience for these 2 categories of data as given in the following table where chi-square equals 0.036 (not significant at the 0.05 level):

A Comparison of Night Collisions

Type	Reflectorized	Control
Rear-end	472	477
Parked	416	413
Total	888	890

Table 8 is a summary of chi-square values obtained for data categories for rear-end collisions. There were no statistical differences from the influences of weather, driver, or vehicle factors on night rear-end collisions. The number of night rear-end collisions of vehicles equipped with reflectorized license plates was not different from the number of night rear-end collisions of vehicles equipped with control nonreflective license plates.

Table 9 gives a summary of the 50 percent probability values for night collisions in Table 10. Vehicles with reflectorized license plates did not have a significantly different night rear-end collision experience than vehicles with control nonreflective license plates.

Figure 2 shows the 50 percent probability test values by directional analysis of night rear-end collisions of the 2 study groups. Vehicles equipped with reflectorized license plates and those with control nonreflective license plates did not have a statistically different rear-end collision experience.

To determine whether reflectorized license plates reduced night rear-end collisions, 4 sets of data were compared. These involved differences in fatal, personal injury, and property damage collisions; rear-end and parked collisions; directional analysis; and driver, vehicle, and weather factors. For all comparisons there were no significant differences between the number of accidents for the reflectorized group and those for the control nonreflective group. It is concluded that the null hypothesis, which states that there is no difference between the reflectorized and control nonreflective groups, cannot be rejected. It is further concluded that the use of reflectorized license plates does not provide a safety advantage by significantly reducing night rear-end collisions.

Table 5. Fifty percent probability test results for daytime rear-end collisions.

Category	Intersection Collision	Non-intersection Collision	Total
Weather			
Clear	6.93[a]	0.18	5.56[b]
Cloudy	0.37	1.31	1.55
Fog	0.44	0.00	0.63
Mist	1.11	0.00	0.70
Rain	0.07	0.19	0.28
Snow	0.27	1.24	1.84
Sleet	0.00	0.00	0.00
Smoke and dust	—	—	—
Not stated	1.14	0.04	0.20
Driving experience			
<3 months	2.29	0.00	0.75
3 to 12 months	0.32	0.00	0.26
1 to 5 years	0.70	0.16	0.08
6 to 10 years	0.88	3.57	0.05
>10 years	3.46	0.84	4.34[b]
Not stated	0.01	0.52	0.51
Age of driver, years			
<16	0.00	—	0.00
16 to 17	0.12	0.00	0.01
18 to 19	0.04	0.13	0.20
20 to 24	2.80	1.70	0.39
25 to 34	1.63	0.14	0.71
35 to 44	1.08	0.00	0.69
45 to 54	0.14	1.12	0.95
55 to 64	0.14	0.61	0.67
65 to 74	0.68	0.83	0.01
>75	0.19	0.00	0.04
Not stated	0.31	0.22	0.02
Age of vehicle, years			
<1	6.08[b]	0.04	3.07
1	2.37	1.19	0.26
2	0.10	0.30	0.41
3	0.38	3.34	0.35
4	9.58[a]	0.37	4.13[b]
5	0.02	5.30[b]	1.62
6 to 10	0.04	2.82	0.78
>10	0.41	0.00	0.36
Not stated	2.04	0.10	1.88

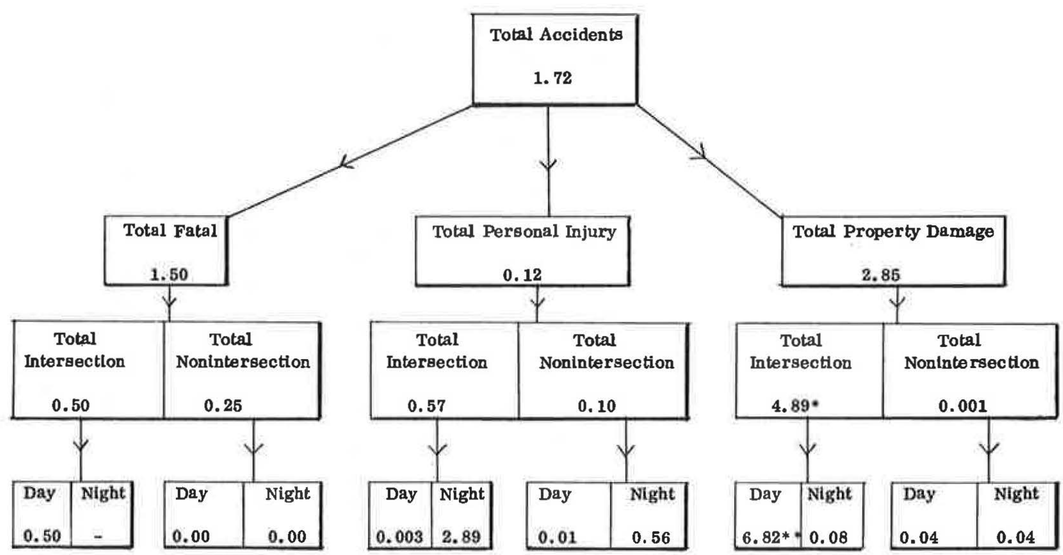
[a]Significant at 0.01 level.
[b]Significant at 0.05 level.

Table 6. Night rear-end collisions.

Category	Reflectorized	Control	50 Percent Test	Calculated[a]
Fatal	0	1	—	6
Personal injury	88	98	0.44	116
Property damage	387	398	0.13	443
Total	475	497	0.45	538

[a]The number of control collisions necessary for a significant difference at the 0.05 level.

Figure 1. Fifty percent probability test values by accident type.



* Significant at the 0.05 level
** Significant at the 0.01 level

Table 7. Fifty percent probability test values for directional analysis of accidents.

	Daytime			Night		
Direction	Fatal	Personal Injury	Property Damage	Fatal	Personal Injury	Property Damage
Intersection[a]						
Both going straight	0.50	0.00	0.00	—	0.07	0.10
One turning right, one straight	—	0.05	3.81	—	0.67	0.00
One turning left, one straight	—	1.07	0.41	—	0.94	0.02
One stopped	—	0.01	0.15	—	0.31	1.19
All others	—	1.64	8.47[b]	—	0.27	0.09
Nonintersection[a]						
Both going straight	0.50	0.08	0.08	—	2.78	0.07
Parked properly	—	0.00	0.82	—	0.03	0.21
Parked improperly	—	0.00	0.24	—	0.00	0.00
One stopped in traffic	0.00	0.00	0.002	0.00	0.00	0.00

[a]All vehicles are in the same direction.
[b]Significant at the 0.01 level.

Table 8. Chi-square values of night collisions.

	Intersection		Nonintersection		Total	
Category	Chi-Square	Degrees of Freedom	Chi-Square	Degrees of Freedom	Chi-Square	Degrees of Freedom
Weather conditions	3.626	3	1.568	3	3.269	5
Driver experience	2.318	4	3.393	3	0.261	4
Driver age	3.441	7	5.746	6	4.585	7
Vehicle age	7.647	7	14.477	8	5.260	8

Table 9. Summary of 50 percent probability test results for night rear-end collisions.

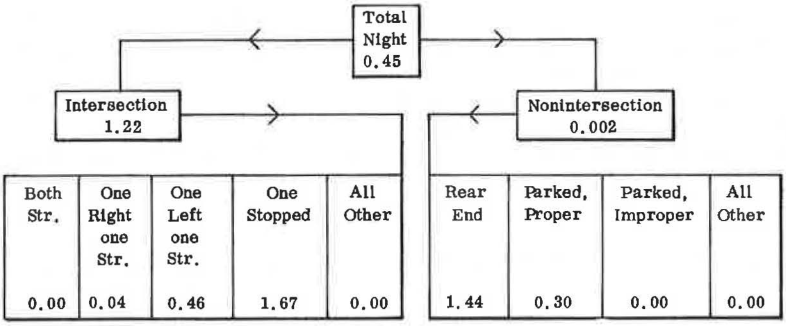
Category	Statistically Different	Not Statistically Different	Total
Weather	0	27	27
Driving experience	0	18	18
Age of driver	0	33	33
Age of vehicle	2	25	27

Table 10. Fifty percent probability test results for night rear-end collisions.

Category	Intersection Collision	Non-intersection Collision	Total
Weather			
Clear	0.15	0.003	0.03
Cloudy	3.74	0.00	1.69
Fog	0.00	0.36	0.64
Mist	0.56	0.27	0.00
Rain	0.02	1.73	0.60
Snow	—	0.57	0.57
Sleet	0.00	0.00	0.00
Smoke and dust	—	0.00	0.00
Not stated	0.25	0.17	0.00
Driving experience			
<3 months	0.00	0.50	0.00
3 to 12 months	0.00	0.00	0.00
1 to 5 years	0.18	0.54	0.00
6 to 10 years	0.63	0.63	0.01
>10 years	1.72	1.45	0.12
Not stated	0.00	0.49	0.37
Age of driver, years			
<16	—	—	—
16 to 17	0.19	0.00	0.03
18 to 19	0.52	2.12	0.02
20 to 24	0.10	2.88	1.73
25 to 34	1.80	0.02	0.88
35 to 44	0.35	0.41	0.00
45 to 54	0.02	0.04	0.12
55 to 64	0.96	0.00	0.43
65 to 74	1.50	0.00	1.78
>75	—	—	—
Not stated	0.02	0.18	0.09
Age of vehicle, years			
<1	0.00	0.00	0.01
1	0.00	0.61	0.43
2	1.82	4.21[a]	0.37
3	0.57	0.79	1.56
4	0.02	0.00	0.01
5	0.31	3.21	0.72
6 to 10	4.30[a]	0.18	0.83
>10	0.13	1.56	0.38
Not stated	0.00	0.76	0.52

[a]Significant at 0.05 level.

Figure 2. Fifty percent probability test values by directional analysis.



INCREASED COST OF REFLECTORIZATION

A recent estimate of the increased costs for reflectorizing license plates has been prepared by the Virginia Division of Motor Vehicles. The increase in costs for the 1974-1975 period is nearly $1.9 million. Virginia is using a multiyear license plate, so the 1976 to 1978 estimate also must be considered. The increase here in costs is over $1.75 million. The 4-year cost increase is over $3.6 million, which represents nearly a 106 percent increase for reflectorizing license plates. A positive benefit-cost ratio does not exist because night collisions have not been reduced for vehicles with reflective plates and the costs to reflectorize plates are high.

SUMMARY AND CONCLUSIONS

The data and analysis given in Tables 1 through 5 show that the accident experiences of the 2 study groups are comparable in those cases where reflectorization would not play a role in accident reduction. It was concluded that the group of vehicles with reflectorized license plates and the group of vehicles with control nonreflective license plates were statistically similar on vehicle, roadway, and driver characteristics, the total number and distribution of day crashes, the total number and distribution of night crashes (excluding the experimental variables), the total number and distribution of daytime collisions, and the total number and distribution of night collisions (excluding the experimental variables).

After the comparability of the 2 groups was established, analyses were performed to see whether reflectorized license plates reduced night rear-end collisions. Accident type; collision type; directional analysis; and weather, driver, and vehicle factors were analyzed to determine whether night differences occurred. No significant differences were found between the 2 groups. It was concluded that the use of reflectorized license plates did not produce a safety benefit through a statistically significant reduction in night rear-end collisions.

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DISCUSSION

William L. Sacks, Consultant, Mansfield, Ohio

In his introduction, the author defines the efficacy of reflectorized license plates to depend solely on their ability to reduce night rear-end collisions. To have been fair, he should have acknowledged that reflectorized plates may afford benefits in (a) other safety situations, (b) increased driver comfort at night by aiding the driver in determining the actual vehicle type and position of an oncoming vehicle with one visible headlight, and (c) assistance to night law enforcement efforts.

Furthermore, the author goes to great lengths to ensure an unbiased distribution of reflectorized and control license plates. But he gives no indication that the study groups are indeed representative of statewide accident experience. When I compared overall study group accident experience with that reported in the 1971 issue of Virginia Crash Facts, some differences emerged. First, 62.96 percent of state accident experience occurred during daylight; but, the reflectorized and control groups showed figures of 71.36 percent and 71.51 percent respectively. Second, by conservative estimate, (multiple-vehicle involvements were reduced by 10 percent), the reflectorized and control groups had 7,887 and 7,817 accidents per 100,000 vehicles; statewide, however, the rate was 6,017 accidents per 100,000 registered vehicles. Third, statewide, 71.5 percent of all accidents involved 2 or more vehicles; the figures for the reflectorized and control groups, however, were 82.1 percent and 82.6 percent respectively. These 3 major differences suggest that neither study group truly represented statewide experience and that the results should not be projected.

The discrepancy in the percentage of all accidents that occurred in daylight may be due to the author's use of time periods to define daytime and night involvements rather than encoded illumination data on his source data file. Why this artificial approximation is employed is not explained. However, this approximation for a vital study aspect could have introduced differences in results that could have changed the author's conclusion.

The author cites the capability of his accident reporting system to differentiate between striking and struck vehicles but nowhere in his analysis does he reference or compare such involvements. Table 6, night rear-end collisions, gives greater totals than does the text table on night comparisons by collision type for supposedly the same data. Because Table 6 makes no reference to parked car collisions, the reader is led to believe that this table may be mistitled and, in fact, that it represents the total for struck vehicles in both rear-end and parked car accidents. The analysis should have included a 2-vehicle accident matrix with 4 types of vehicle (reflectorized, control, other Virginia, and all others) and 2 types of involvement (struck and striking). At minimum, the analysis should have pursued the involvement according to light conditions and collision type of study group vehicles as both the striking and struck vehicles.

Review of the study is made difficult by the many tabulations that offer chi-square values rather than actual frequencies. Much of the reader's difficulties could have been avoided had full accident frequency tables for all data subjected to statistical comparison been included.

A major factor weakening the report conclusion is the difference in results presented for daytime and night data. Table 2 shows the reflectorized group to be involved in 1,620 daytime rear-end collisions and the control group in 1,510. Although this difference does not satisfy a 0.05 level test, it comes exceedingly close. In fact, if there had been 1 more daytime rear-end collision in the reflectorized group, the difference would have been significant at better than the 0.05 level. When this is coupled with the night rear-end experience for the 2 groups (472 and 477 involvements for the reflectorized and control groups respectively) it becomes difficult to accept the conclusion that both daytime and night rear-end collision experience are similar for the 2 groups. The data suggest a greater propensity for rear-end collisions in the reflectorized group independent of license plate type. This alone is adequate to invalidate the author's conclusion.

If one accepts the conclusion that there is no significant difference (at the 0.05 level) between the 2 groups in either daytime or night rear-end experience, then one would expect that the numerical difference between daytime and night experience (day minus night) is also statistically insignificant. These differences in day over night experience are 1,148 (1,620 minus 472) and 1,033 (1,510 minus 477) for the reflectorized and control groups respectively. When these are tested by the 50 percent probability test, the resultant chi-square value of 6.06 indicates the differences to be statistically significant at better than the 0.05 level.

Parked car involvements were not included in the previous analysis (although the result would have been the same with a chi-square value of 4.66) because many parked car collisions involve side-to-side or side-to-corner vehicle contacts when the license plate on the parked car is not visible or is of no meaning to the driver, such as in a parking or unparking maneuver or when an out-of-control vehicle sideswipes a parked car.

Other major points that cause me to reject the study conclusion concern

1. The 0.05 statistical significance level used by the author,
2. The discovered differences in accident involvement frequencies, and
3. The difference needed for a break-even investment for reflectorized license plates to be justified solely by night rear-end collision reduction.

Assume an annual extra cost for reflectorized license plates of $0.20 per vehicle. For 100,000 vehicles the total annual investment is $20,000. If an average night rear-end collision has societal costs of $1,850 (computed by weighting U.S. Department of Transportation unit accident severity costs by the severity frequencies offered in Table 6), the required rear-end accident reduction for break-even investment is 11 collisions per year. However, in Table 6 the author calculates a needed difference of 63 rear-end collisions to satisfy a 0.05 significance level. Thus, what the author is really doing through his choice of significance level is demanding that a benefit-cost ratio of 5.7 (63/11) exist before he will acknowledge the value of reflectorized license plates. If a true benefit-cost ratio of, say, 3.0 existed, the author's test would not have the sensitivity to detect the wisdom of the investment.

B. J. Campbell, in his North Carolina work, which is cited by Stoke, cautioned about this sensitivity problem when he wrote

> It would seem in this study a generous significance level is warranted. The consequences of concluding that there is significant improvement when in fact there is not (Type I error) are less serious in a relatively low-cost program such as this. On the other hand, the consequences of concluding

> that the program is ineffective when in fact it *is* effective (Type II error) is more serious. This is because a Type II error could lead to a recommendation that the program be cancelled, thus saving one third million in the state budget; but, this would allow comparable costs to be Incurred in more accidents, death and injury.

Just why the author failed to heed Campbell's advice is not answered in his report.

Attention is now called to the author's quotation from the North Carolina study. As quoted by the author, it reads, "Circumstances of sample size and unavoidable limitations of study design preclude assertion that the effectiveness of reflectorized plates has been proved in an absolute sense." From this quotation it would appear that the North Carolina study recommended against reflectorized plates. However, this is not the case. The full quotation reads as follows:

> While circumstances of sample size and unavoidable limitation of study design preclude assertion that the effectiveness of reflectorized plates has been proved in an absolute sense; nevertheless, we feel that North Carolina is justified in continuing the program since the best evidence indicates that reflectorized license plates can reduce accident costs by an amount that is about twice the added cost of the plates.

In summary, I find it necessary to reject the study conclusion that reflectorized license plates do not reduce night rear-end collisions for the following reasons:

1. The use of arbitrary time periods rather than existing day-night classifications introduces error potential perhaps greater than the real differences being sought;
2. The discovered greater propensity for day rear-end collisions within the reflectorized group was neither recognized nor considered in the analysis; and
3. Statistical test requirements were shown to be far too severe because they precluded finding any economic benefits under a benefit-cost ratio of almost 6 to 1.

R. C. Vanstrum, 3M Company

The author in his acknowledgments states, "... researchers from the 3M Company, whose review of an early draft of the report led to the acquisition of additional data, are recognized for their comments on the proposed study methodology." This might imply 3M's agreement with the actual study methodology and the final report. This is not the case, and the following comments explain why we disagree with the author's methodology and conclusions.

As originally proposed, the study design not only included the 2 study groups, reflective and nonreflective, but also a comparison with the rest of the state. Further, it included a separation of the data into struck and striking car categories. The original study plan that we reviewed was subsequently given up and a more incomplete one substituted.

We studied the rest of the state accident data over the same approximate time period as the study using published state data for 1971 (8). (State data for 1970 and 1972 were also reviewed and the data, reduced to a 100,000-vehicle basis, showed no major trends. Minor adjustments in the figures can be made to convert study vehicle involvements to crashes (a conservative 0.90 factor was used), and the relationship of accident experience for all vehicles to that of passenger cars can be taken into account. [Passenger cars in Virginia account for 83.3 percent vehicle registration and 84.4 percent of vehicle involvement (8).] These adjustments produce greater agreement between study groups and the state data. But, even with the crash data adjusted, the 2 study groups do not agree at all with the rest of the state on a 100,000 vehicle basis. On the average, the study groups are involved in about 28 percent more accidents than for the state as a whole. Other comparisons can be made that show major differences. The question is raised, which data are correct, those of the state of Virginia or those of the license plate study? Is Virginia underreporting total accidents and not correctly reporting subcategories or did the study group statistics get "special treatment"? The type of special treatment given the 2 study groups could decidedly influence the results.

The struck and striking car categories, if they are differentiated in the data at all, are not clearly indicated in the report. In fact, there is virtually no mention of this important consideration except to say, "The reporting format distinguished between the striking vehicle and the vehicle struck." This distinction is not applied to any of the data. In the text table on night comparisons by collision type, the author discusses parked car data especially. It is implied that this table represents struck car data because striking car data or combined data would not directly relate to the effect of reflectorization. In referring to the parked car, the author states, "The data category for parked cars is especially noteworthy because it is the one where the struck vehicle is usually unlighted" (emphasis added). Table 6 is titled night rear-end collisions. According to data we reviewed in an earlier draft, Table 6 contains the struck car data for the entire directional analysis of the study obtained from 9 state police accident report categories, which were described earlier in the paper. Table 6, then, includes struck data for both parked and rear-end collisions although they are not labeled as such. What then is the text table on night comparisons by collision type? If it is struck vehicle only, how does one reconcile the different numbers? If it is struck and striking combined, why is it presented in such a fashion that it implies that it is for struck cars only? If it is struck and striking combined, the author is not justified in making the comparisons which he makes; furthermore, the data do not relate to the questions raised by the study. And, why aren't technical definitions for rear-end accidents used rather than the inconsistent and nontechnical words "parked" and "rear-end"? Most importantly, why doesn't the author clearly label the data?

Another point we objected to in the study methodology was the arbitrary time periods (6:00 p.m. to 6:00 a.m. and 9:00 p.m. to 6:00 a.m.) to describe periods of darkness. Light conditions are encoded in crash reporting data by the state and could have been used. The approximation introduced by using arbitrary time periods introduces over 13 percent error in categorizing accidents by light conditions during the high traffic volume hours of 5:00 to 9:00 p.m., nearly 25 percent error during the hours of 5:00 to 7:00 a.m., and over 10 percent error during the total period of darkness. This is based on an analysis of sunrise and sunset times for 1 locality only (a half hour after sunset to a half hour before sunrise was used for darkness). Even greater variation would be encountered across the entire state. This point alone throws considerable doubt on the accuracy of determining what actually was a day accident or a night accident.

The author provides a number of tables to show that the 2 study groups are identical except for the test variable. In overall statistics they appear quite similar; but, in daytime rear-end accidents in Table 2, a category of special interest to the study, the difference between 1,620 for reflective plates and 1,510 for control lacks only 1 accident to be significant at the 0.05 level. This points to a basic difference between the 2 groups. Table 2 appears to include struck and striking data combined. What about struck car only data? Tables 4 and 5 presumably contain this information although they are not explicitly labeled. They give only the results of the statistical tests. The actual data in the earlier draft show that 7 daytime sets with significant differences in the final report all had reflective plates high. The significant category in Table 3 also has reflective plates high in daytime intersection accidents. Because there is no noticeable visual difference between a reflective plate and a nonreflective plate in the daytime, the idea that a factor other than the license plate visibility was different between the 2 study groups is substantiated. If this different factor exists in the day, what assurance do we have that it does not also exist at night? If the variation was caused, for example, by greater exposure of the reflective plate group in the day producing more daytime rear-end accidents and this same variation was operative at night, then, in the absence of any safety effect from the reflective plate, one would expect more accidents for the reflective plate at night also. This is not the case as given in Table 6 and Table 10, age of vehicle category. The latter contains 2 significant sections (numbers and direction again not noted by the author). The earlier draft reveals they both have reflective plates low with 1 in the 6- to 10-year-old category and the other in the 2-year-old category. The actual numbers show 21 fewer accidents in the 6- to 10-year-old category and 19 fewer in the 2-year-old category. Because they are mutually exclusive they can be added to produce a total of 40 fewer accidents at night for the reflective plate group. This is almost 4 times the accident reduction needed to cost justify the reflective plate program.

Costs can be computed by assigning an additional annual cost of 20 cents (12 cents for initial issue and 8 cents for replacement and other expenses) per vehicle for reflective plates to give a total additional annual cost of $20,000 for 100,000 vehicles. The cost of a Virginia night rear-end accident can be computed by severity ratios in the appropriate directional categories as given in the state police accident report mentioned previously, by using state and study data coupled with U.S. Department of Transportation accident cost figures. The cost is over $1,800 for each night rear-end accident. The break-even point for 100,000 vehicles is $20,000/$1,800 or approximately 11 fewer accidents. It should be noted that the significance level for rear-end accident reduction in this study is 63 accidents (from Table 6, 538 minus 475) or over 5 times that which cost justifies the program. The "statistical significance" on which the study revolves does not agree with practical significance.

The author adds a brief paragraph on the increased cost of reflectorization. It would have been useful if he had given a full disclosure of actual numbers instead of selected data. For example, it would be germane to indicate that the increased costs of $3.6 million for 4 years applies to the manufacture of 7,800,000 license plates over this period. These include 3,300,000 annual license plates which the source report indicates have 2.7 times the additional cost for reflectorization as multiyear plates. The additional cost of reflectorization is more accurately represented by the lower cost option, the multiyear plate, which the source report quoted indicates has a 10 cents per plate annual additional cost over a 6-year period. This agrees with the 20 cents additional cost per vehicle.

The author states, "A positive benefit-cost ratio does not exist." It is assumed what was meant was that a benefit-cost ratio of 1 or greater does not exist (the cost-effective break-even point). Nowhere in the data is there justification for this statement. The statistical limitations of the study sample size allow this statement to be considered only at benefit-cost ratios appreciably higher than 1. The author can make no conclusions below a benefit-cost ratio of 3/1 even if the very conservative National Safety Council accident cost figures, which, when combined with severity ratios, show the cost of a 1971 Virginia night rear-end accident to be over $1,000, are used. (On a 100,000 vehicle, $1,000 basis, a 20 accident reduction would be needed to equal $20,000; but there would be no detectable benefit according to the author's criteria of a 63 accident reduction.)

Based on the foregoing, we believe that there are a number of inconsistencies in this study that should prevent anyone objectively reviewing the data from concurring with the author's sweeping generalizations. If anything, a small safety effect from reflective plates does appear in the data. Although small, and one would not expect a large safety effect from a single device of this sort, this safety effect is more than enough to cost justify the program from the safety standpoint alone without considering any other benefits.

AUTHOR'S CLOSURE

I am indebted to the discussants for reviewing this study. They correctly point out that the study is not explicit on the categories "striking" and "struck" in tabulating the data. I assumed that it would be clear that all data and statistics in the report involved only vehicles that were struck.

I also agree that more definitive titles could have been used for Table 6 and the text table on night comparisons by collision type. The data in Table 6 include both rear-end and parked collisions as defined in the state police accident report, but only for primary collisions—that is, the first vehicle struck. In multiple vehicle collisions, only the vehicle first struck was used for analysis. In the text table on night comparisons by collision type, all experimental and control vehicles involved in a collision were counted and used for the statistical analysis. The significant factor in night multivehicle collisions and night primary collisions is that no differences existed between the 2 groups for the collision experience of the struck vehicles.

Sacks, in his opening remarks, takes exception to the stated purpose of the study. He states that other factors should also be considered. Because the noncollision benefits to which he alludes are without foundation in evaluative research, I chose to investigate whether reflective plates could produce a measurable reduction in night rear-end collisions. The other benefits described by Sacks were not included in the study because this author believed, and still believes, that investigating them would be unlikely to produce quantifiable or meaningful results. On "assisting night law enforcement efforts"—results from a previous report by Stoke and Simpson (1) that studied the legibility distances of reflective and nonreflective license plates showed that the increased legibility distances do not appear to significantly increase the time available to read and record license plate numbers. At a closing speed of 60 mph there is a gain of less than $\frac{1}{5}$ second to the rear and $\frac{1}{3}$ second for an approaching vehicle. If 2 vehicles are approaching each other at a speed greater than 30 mph, this time is even further reduced.

Sacks calls attention to 1 of the quotes that was used. It was taken from page 40 of the June 1968 Traffic Safety Research Review (6), and was used to show that Campbell and Rouse recognized the limitations of their research and recommended a design similar to the one used for the current study. But, the North Carolina study apparently is viewed differently by its authors and by Sacks about research design, timing of the study (evaluation after initiation), and the encompassing nature of the findings.

Vanstrum, who has been in constant contact with me since the beginning of the study, and at whose suggestion the daytime analysis was added to the study, objects to the use of time periods to delimit periods of light and darkness. (I am not sure why an objection is raised at this time when it was not a concern in June 1972.) Time periods were used because I believed that an investigating officer is rarely able to arrive on the scene of an accident immediately on its occurrence, and therefore he or she cannot reasonably say what the lighting conditions were at the time of the accident. The use of time periods reflects when the accident occurred and not when the investigation of the accident took place.

The discussants made no attempt to account for accidents that occurred during dusk and dawn, and those for which no information was checked. Statewide data including accidents occurring during daylight, dusk, and dawn show that 68.25 percent of the total accident experience involved these categories as opposed to 71.36 percent and 71.51 percent for the study groups.

In his analysis on percent of error using time periods, Vanstrum uses different time periods than were used in the study itself. The point that factors that influence automobiles with reflectorized license plates would also influence automobiles with control nonreflective license plates was overlooked. A 10 percent overcounting of daylight collisions in the study would produce a conservative error in favor of reflectorized license plates. When computations were carried out to modify the data by 10 percent there were no statistical differences for day or night between the 2 study groups.

The mathematical computations and the assumptions made by the discussants warrant comment. First, all data for the study were collected in the normal manner for the state, and it was only when the accident report forms were received by the Virginia Department of State Police that their control or reflectorized status was recorded, thus ensuring unbiased reporting. Second, the study occurred during a registration year, March 15, 1971, through April 15, 1972; the discussants compared these results to 1971 calendar year crash data. Third, the study was concerned only with private passenger vehicles (fleet and commercial vehicles were excluded); Virginia Crash Facts tabulates all passenger vehicle data together. Finally, simply dividing total accidents by registered vehicles assumes that all accidents involved only a single vehicle and that no vehicle was involved in more than 1 accident during the reporting period. The study was based on how many control or reflectorized vehicles were struck; the critiques are concerned with a ratio of total accidents to registered vehicles. There is more than a difference in semantics involved, for the method used by the discussants undercounts accident involvement.

Sacks quotes at length from the North Carolina study in an attempt to show that the current study used too severe a significance level to determine effectiveness. He fails to point out that Campbell's advice (contained in a footnote and referring to his own study) is for studies of "... a small sample and a weak study design..." (6, p. 18). The study under discussion had a large sample and a strong study design; therefore, the advice does not apply. Analyses must set critical statistical limits for the determination of effectiveness. Collision reduction benefits must be real rather than promoted or advertised.

The discussants draw attention to 1 data cell in Table 2, that of daytime rear-end collisions. The report is concerned with night rear-end collision reduction analysis, which includes the parked categories. To have a comparative equivalency during daytime, parked collisions must be combined with rear-end collisions. The computation of the 50 percent probability value for this combined daytime data yields $X^2 = 2.69$, which does not reach the 10 percent level. One additional daytime collision has no effect on the conclusion that there is no difference between the control and experimental groups in cases where reflectorization does not play a role.

The fallacy of treating partial data is exemplified by the head-on collision section of the study. The ratios of the collision figures, although reversed by type of collision for the reflectorized and control groups, are similar for both sets of data. The reflectorized group had fewer daytime but more night head-on collisions, and the control group had fewer daytime but more night rear-end collisions. It is important for the reader to note that in both cases differences in the number of collisions between the reflectorized and control groups were not greater than would be expected by chance. I am not suggesting that this individual cell (Head-On) has more meaning than any other cell; I am showing the pitfalls encountered when individual cells from distributions of data are treated as separate entities. The following are day-night ratio comparisons:

Collisions	Daytime		Night	
	Number	Percent	Number	Percent
Head-On				
Reflectorized	591	48.9	249	50.4
Control	617	51.1	245	49.6
Rear-End				
Reflectorized	1,620	51.8	472	49.7
Control	1,510	48.2	477	50.3

Vanstrum's comments on the increased costs to reflectorize license plates exemplifies the approach used throughout his discussion of the study. An attempt is made to obscure the report findings by reciting nonessential facts. Cost figures for both painted license plates and for reflectorized license plates were based on identical numerical requirements for the years 1974 to 1978. The issuing of multiyear plates was also included as part of the cost analysis. The Virginia Division of Motor Vehicles estimate of costs (9) for the 4 years under discussion showed painted license plates to have a total cost of $3,415,500 and reflectorized license plates to have a total cost of $7,034,000. Simple arithmetic gives the total increased cost ($3,618,500) for reflectorizing license plates. Vanstrum attempts to decrease the effect of the total increased cost by presenting sheeting costs amortized by single license plate unit costs over a 6-year period. (Virginia does not use and has not proposed to use a 6-year plate.) The use of a pennies per day argument neglects the fact that they accumulate to large sums over time.

In regard to the cost-benefit analysis of a reflectorized license plate program, I computed the average cost of a rear-end accident in 1971 for the state of Virginia to be $907 by using the National Safety Council figures for costs of accidents. According to this figure and the Virginia Division of Motor Vehicles estimated cost for reflectorizing license plates, the needed decrease in passenger vehicle night rear-end collisions must be 1,029 per year for a 2-million passenger-vehicle population. This figure is very different from the discussants' 11 collisions per 100,000 vehicles per year (1,029 versus 220). For all types of crashes in both urban and rural locations, rear-end collisions are the least severe and therefore the least costly accidents (10, 11); head-on collisions are the most costly type of collision in terms of lives lost and injuries suffered.

The discussants have not presented any information that would lead to a conclusion other than that there was no difference in the night rear-end collision experience between the experimental and control groups. The major sales point for reflectorized license plates has been their collision reducing potential, and this purported potential has not been realized. If reflectorization does not reduce night collisions, no other discussion is necessary. Attempting to determine whether the benefits are worth the cost when there are no benefits is a nonsensical exercise.

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