centage of lane changing and encroachments was significantly higher during rain without the markers but not significantly different from dry conditions when the markers were placed. This is important documented evidence that raised markers provide significant guidance to motorists under adverse weather conditions, when the visibility of painted lines is severely reduced.

That the markers caused reductions in erratic maneuvers at lit and unlit sites was an unexpected occurrence. This result occurred for each type of site--curves, exits, and bifurcations. This suggests that the treatment of areas with overhead lighting such as intersections and interchanges can provide a safety benefit to motorists and should not be excluded from consideration for the sole reason that they are lit.

Due to the expense of installing SRPMs, decisions have to be made about where and when the markers should be used. Whether spot treatments of locations that are considered hazardous or entire roads should be marked could be the subject of future research, perhaps considering the cost/benefit ratio of each situation if it can be shown that accidents are reduced by the placement of SRPMs. Research may also be useful in choosing among the use of the markers on Interstate and primary highways or two-lane rural roads. Although the former would most likely have higher vehicle miles of travel per lane mile of marked roadway, the dark, winding nature of many rural roads, and the presence of fixed obstacles near to the roadway may point to their being considered a higher priority.

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STOP Sign Versus YIELD Sign

HARRY S. LUM AND WILLIAM R. STOCKTON

This paper investigates the relative effectiveness of STOP and YIELD signs at low-volume intersections (less than 500 vehicles/day on minor roadway) in rural and urban environments. Traditional rationales for installing STOP signs, such as inadequate sight distance and high volumes on major roadways, are examined. It is shown that the current use of STOP signs is unrelated to sight distance availability and that STOP signs do not categorically reduce accidents at low-volume intersections. Further, no relation is demonstrated between accidents and major roadway volumes up to 6000 vehicles/day. STOP signs are shown to increase road user costs by more than 7 percent over YIELD signs.

The STOP sign is by far the most prevalent traffic control at intersections. Its message is simple and clear, and the expected response of motorists is a complete cessation of motion (1). The distinct color and shape of the STOP sign result in quick recognition by motorists. Despite its clear meaning, Stockton and others (2), in a study sponsored by the Federal Highway Administration (FHWA), reported that less than 20 percent of the motorists voluntarily complied by completely stopping at STOP signs. (Motorists who had to stop at a STOP sign because of traffic conditions were excluded from the computation.) This compliance rate of 20 percent represents an overall average of three states: Florida, Texas, and New York. A total of 140 intersections in urban and rural environments were sampled. At least one roadway had average daily traffic (ADT) of 500 or fewer vehicles; major road volume ranged up to 36 000 vehicles/day and did not meet the Manual of Uniform Traffic Control Devices (MUTCD) (3) volume warrants for traffic signals.

Dyar (4) also investigated driver's observance of STOP signs at rural and urban intersections in South Carolina. He reported a voluntary compliance rate of 11 percent. Stockton, however, noted that the difference in compliance rates among the three states studied was significant. Such low compliance rates indicate that STOP signs are being used indiscriminately; hence, the sign's purpose of providing for orderly and predictable movement of traffic is defeated.

MUTCD REQUIREMENTS

MUTCD states that (3), to be effective, a traffic control device should meet five basic requirements:

1. Fulfill a need;
2. Command attention;
3. Convey a clear, simple meaning;

4. Command respect of road users; and
5. Give adequate time for proper response.

In practice, the second, third, and fifth requirements are generally met without difficulty. The fourth is dependent on the first requirement, which, of course, is the most critical one. In the eyes of the motoring public, the need must be visible and real, not merely perceived by the traffic engineer or unknowledgeable citizen groups or associations. Excessive and indiscriminate use of STOP signs eventually breeds disobedience and contempt for law enforcement.

The MUTCD warrants provide broad guidelines for the use of two-way STOP control. A STOP sign may be warranted at an intersection where one or more of the following conditions exist (3):

1. Intersection of a less important road with a main road where application of the normal right-of-way rule is unduly hazardous;
2. Street entering a through highway or street;
3. Unsignalized intersection in a signalized area; and
4. Other intersections where a combination of high speed, restricted view, and serious accident record indicates a need for control by the STOP sign.

Conditions 1, 2, and 3 deal with the assignment of right-of-way at an intersection. STOP and YIELD signs both have that function, but the YIELD sign is less restrictive in that all traffic does not have to come to a complete stop. Condition 4 is vague and is open to the engineer's interpretation as to when a STOP sign should be used. Unlike signal warrants, guidelines for quantification of the variables [e.g., speed, restricted view, volume (not stated), accident record] are not discussed.

Warrants for YIELD control are somewhat vague (3):

1. On a minor road at the entrance to an intersection where it is necessary to assign right-of-way to the major road, but where a stop is not necessary at all times, and where the safe approach speed on the minor road exceeds 10 mph;
2. On the entrance ramp to an expressway where an acceleration lane is not provided;
3. Within an intersection with a divided highway, where a STOP sign is present at the entrance to the first roadway and further control is necessary at the entrance to the second roadway, and where the median width between the two roadways exceeds 30 ft;
4. Where there is a separate or channelized right-turn lane, without an adequate acceleration lane; and
5. At any intersection where a special problem exists and where an engineering study indicates the problem to be susceptible to correction by use of the YIELD sign.

The first four conditions are fairly straightforward for the application of the YIELD signs; however, it is not clear as to what is meant by "problem to be susceptible to correction by use of the YIELD sign."

Without specific guidelines to follow, the problem of when to use STOP or YIELD signs becomes one of interpretation of the word need by the individual traffic engineer. It would not be surprising then if the views of engineers differ on the need for STOP or YIELD signs. Tables 1 (2) and 2 (2) give criteria for the application of STOP and YIELD signs by six different traffic agencies. They all agree that sight distance is a critical criterion for STOP control; they disagree as to what the critical approach speed (distance) should be.

Sight Distance

A recent study evaluated the effect of sight distance on choice of control. The sight distance standard used was the American Association of State Highway and Transportation Officials (AASHTO) case 2 (5) requirements. AASHTO case 2 sight distance requires that drivers on all approaches have sight distance sufficient for the relative approach speeds to detect a vehicle on a conflicting approach and stop prior to entering the intersection. Since most of the approaches studied had approach speeds in excess of 25 mph (40 km/h), this test was considerably more conservative than the 10 mph (16 km/h) requirement of the manual (3).

Table 3 gives the frequencies of control types used at 179 approaches (140 intersections) for varying degrees of available sight distance. Sight distance availability is defined as the ratio of available sight distance to the required AASHTO case 2 sight distance. An index value of 1.0 indicates adequate sight distance.

The supposition that STOP signs are used at intersections where sight distance is poor is not supported by the data. Table 4 gives an analysis of the data presented in Table 3. Two null hypotheses are tested: (a) STOP and YIELD signs are used independently of sight distance, and (b) whether an intersection is controlled (STOP and YIELD) or uncontrolled is independent of sight distances.

The minimum discrimination information statistics (MDIS) are both less than the tabulated χ^2 value of 7.841 for 3 df at the 5 percent significance level. Hence, the hypotheses are not rejected. STOP control at low-volume intersections is used in spite of adequate sight distance, and uncontrolled intersections are as likely to have poor sight distance, at least in practice.

With respect to driver behavior, we hypothesized that voluntary stop rate would increase as sight distance decreases. Voluntary stop rate was based on the percentage of drivers who stop in the absence of a conflicting major road vehicle. A regression analysis of voluntary stop rate versus sight distance showed a very poor relation ($r = -0.126$).

Voluntary stop rates were very low for all control types studied (stop = 19 percent, yield = 8 percent, no control = 9 percent). Drivers were observed to slow down to whatever speed was required to evaluate the safety of entering the intersection before choosing a course of action. This behavior appeared to be consistent across all levels of sight distance and control type. Observations of more than 3000 individual movements were made at 140 intersections. Of these, only a small portion exceeded a 5-mph (8-km/h) entry speed (stop = 17 percent, yield = 13 percent, no control = 11 percent). Though not tabulated, most of the entries at speeds greater than 5 mph (8 km/h) were made at less than 10 mph (16 km/h). Therefore the imposition of a 10-mph (16-km/h) sight distance criterion ignores the propensity of the vast majority of drivers to slow well below that speed. Further, it unnecessarily restricts the application of yield and no control at locations where there is no evidence that stop control is superior.

Accident Experience

Does the use of STOP signs help to reduce accidents at low-volume intersections? Table 5 was compiled from Stockton's data (2). The entries in the table represent the number of intersections that experience a given number of accidents over a three-year period (1975-1977, inclusive). The table shows that STOP-controlled intersections exhibit a higher

Table 1. Stop control application criteria other than or in addition to MUTCD criteria.

Location	Volume	Accidents	Sight Distance Criteria	Other
Delaware		Two accidents correctable by STOP within 12 months	Safe approach speed < 24 mph	Minor approaches at school crossings; stop control may be applied on major if more than 2500 ft from previous STOP or YIELD or if minor approach serves 15 or more homes
New York State			Critical approach speed < 8 mph	
North Dakota	Major approach ADT >150 or total ADT >250		< AASHTO case 2	
Baltimore, MD	Major volume >100 vehicles/h		Safe approach speed <5 mph	
		2 in 5 years and sight distance criteria	Safe approach speed 5-10 mph	
		2 in 1 year or 3 in 5 years and sight distance criteria	Safe approach speed >10 mph	
Concord, CA	Major volume >1000 vehicles/day (or 100 vehicles/h) and minor volume >500 vehicles/day (or 50 vehicles/h)	4 in 1 year	Critical approach speed of ≤10 mph	
	Major volume >500 vehicles/day (or 50 vehicles/h) and minor volume 250 vehicles/day (or 25 vehicles/h) and/or accident and sight distance criteria	2 or more within 1 year and/or volume and sight distance criteria	Critical approach speed <15 mph	Two or more criteria must be met
Montgomery County, MD			Sight distance along major approach from 35 ft back; on minor approach, <125 ft	

Table 2. Yield control application criteria other than or in addition to MUTCD criteria.

Location	Volume	Accidents	Sight Distance Criteria	Other
Delaware				Minor approach serves 5 or more homes
New York State			Critical approach speed >8 mph	
North Dakota	<150 vehicles/day on major approach and sight distance criteria		> AASHTO case 2 modified for rural and urban separately and other criteria	Rural, gravel roads only; urban, city streets only
Baltimore, MD				At intersections where STOP is not warranted
Concord, CA	Major street, 500 vehicles/day or (50 vehicles/h); peak and minor street, 250 vehicles/day (or 25 vehicles/h) peak	Two or more of correctable type in 12 months if only STOP warrant met	Critical approach speed between 15 and 20 mph	
Montgomery County, MD			Sight distance along major from 35 ft back; on minor, >125 ft	Some control dictated by geometrics, accidents, or volumes

proportion of intersections that have one or more accidents. Had the one-accident intersections been reported for the uncontrolled classification instead of the STOP-controlled classification, it would lend support to the contention that STOP control helps to prevent accidents.

One possible explanation for this deviation from the expected is that STOP signs were erected after an accident had occurred. However, a rechecking of the records did not indicate such was the case. A second possible explanation is that STOP signs were installed at hazardous intersections. Accident records and field visits to these intersections revealed no evidence of potential hazards. Another possible explanation is that the unusual number of accidents at these STOP-controlled intersections occurred at high-volume intersections. The table below (2) gives the distribution of one-accident intersections by volume and control type. The low cell frequencies preclude statistical analyses. It is certainly unconvincing that STOP signs were used at high-volume intersections.

Volume (vehicles/day)	STOP Sign	YIELD Sign
0-1000	7	1
1000-2000	2	0
2000-3000	1	1
3000-4000	3	1
>4000	0	1

Our interpretation is that accidents at low-volume intersections are rare events, but over a period of time, an accident will occur. In Table 5 each control type shows two intersections that had three or more accidents. Our conclusion is that stop control at low-volume intersections does not categorically help to reduce accidents.

Table 3. Distribution of control type by sight distance at 179 approaches.

	Sight Distance Index				
Control Type	0-0.5	0.51-1.0	1.01-1.5	>1.5	Total
STOP	18	26	16	9	69
YIELD	7	27	17	11	62
Uncontrolled	11	14	16	7	48
Total	36	67	49	27	179

Table 4. Analysis of information table for data presented in Table 3.

Component	MDIS[a] ($2\hat{I}$)	df
Independence between STOP and YIELD control	4.885	3
Independence between control and no control	2.338	3
Total independence	7.223	6

[a] In this paper Kullback's information-theoretic approach to the analysis of contingency tables was used instead of the conventional Pearson's chi-square test. The minimum discrimination information statistics (MDIS) whose symbolic representation is $2\hat{I}$ and is asymtotically distributed as χ^2 for large sample and for a wide class of problems (6, p. 393). The formula used to calculate $2\hat{I}$ is $2[\Sigma_i \Sigma_j n_{ij} \ln(n_{ij}) + n \ln(n) - \Sigma_i n_i \ln(n_i) - \Sigma_j n_j \ln(n_j)]$, where $\Sigma_i n_i = \Sigma_j n_j = n$.

Table 5. Distribution of accident frequency by intersection and control type.

	No. of Accidents				
Control Type	0	1	2	≥3	Total
STOP	33	13	0	2	48
YIELD	40	4	2	2	48
Uncontrolled	42	0	0	2	44
Total	115	17	2	6	140

Table 6. Distribution of intersections with accidents by major road volume.

	No. of Intersections		
ADT	Without Accidents	With Accidents	Total
0-1000	68	10	78
1001-2000	12	1	13
2001-3000	9	4	13
3001-4000	7	1	8
4001-5000	2	3	5
5001-6000	4	0	4
>6000	13	6	19
Total	115	25	140

Major Roadway Volume

Both YIELD and STOP signs have the function of assigning the right-of-way, generally to the roadway that has the higher volume. Data collected by Stockton (2) on major roadway traffic varied from 1000 to 36 500 ADT. To determine if there is a relation between volume and accident experience, Table 6 (2) was constructed. Volume was grouped by increments of 1000 ADT except for the last group, which included all intersections with more than 6000 ADT. The total MDIS of 12.0833 is slightly less than the tabulated χ^2 value of 12.6 for 6 df at the 5 percent significance level, which indicates that there is no relation between accident experience and traffic volume.

Our tentative conclusion is that, up to 6000 ADT, the YIELD or the STOP sign may be used to assign the right-of-way. It is not clear, however, that the 6000 ADT is the upper bound of no association between intersection accidents and traffic volume. It will have to be established in future studies how much higher than 6000 ADT the upper bound might be.

PAST SIGNING PRACTICE

Signing for traffic control, unlike signalization, is passive; it cannot accommodate changing traffic conditions. Understandably, the traffic engineer with safety uppermost in his or her mind, would choose the normally conservative but more restrictive STOP sign in preference to the YIELD sign. This may have been acceptable engineering practice years ago, but the proliferation of STOP signs has made drivers skeptical and disbelieving of a need for the STOP sign when they see one. Dyar (4) reported no significant difference in driver's observance of STOP signs with or without special control measures at rural intersections with inadequate sight distance. It is not clear from the report whether these special control measures were used at selected hazardous intersections. The special control measures included

1. STOP sign larger than the standard 30-in sign,
2. STOP signs installed on both the left and right shoulders of the controlled approach,
3. Red flashing lights at STOP-controlled approaches and amber flashing lights for through streets,
4. Larger rectangular overhead sign with the word STOP suspended above the intersection, and
5. Combinations of the above.

It is evident that the STOP sign has lost its meaning. Drivers treat it as a YIELD sign--slow down and then proceed with caution.

YIELD SIGN

The YIELD sign (trapezoidal) was introduced in 1951 in Tulsa, Oklahoma, and incorporated into the 1955 revision of the national MUTCD as an equilateral triangle with one corner pointed downward with black lettering on a yellow background (7), which was later changed to the now familiar red on white. It is less restrictive than the STOP sign and definitely assigns the right-of-way to the major road. The Supreme Court of South Dakota ruled that [State v. Muhs, 137 N.W., 2nd 237, 239 (S.D., 1965)]:

> The only difference between a STOP sign and YIELD sign is the duty always exists to stop and look effectively (at) the STOP sign, and for a YIELD sign the duty is to slow down, effectively look to see if the highway is free from oncoming traffic, and stop if necessary to yield the right-of-way....

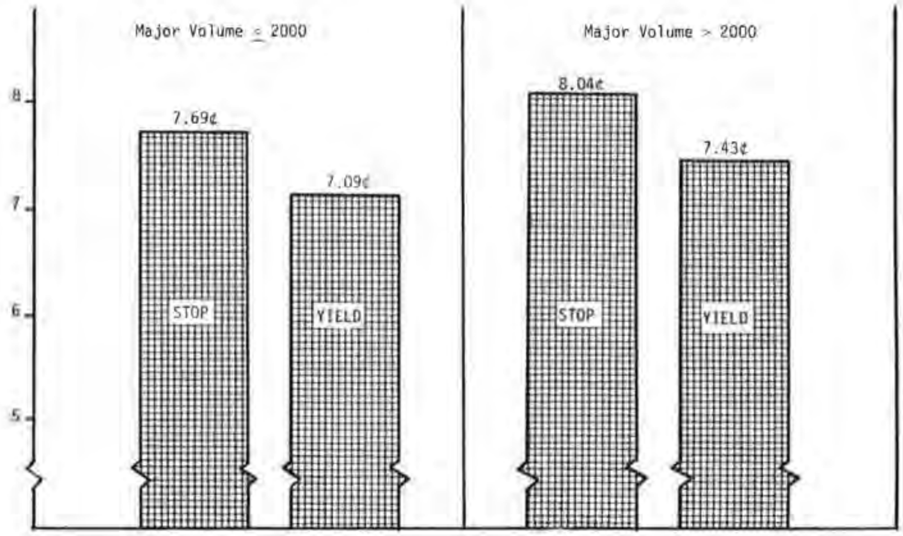
Then, why is the YIELD sign not in greater use? There are several reasons:

1. The application of YIELD signs would require engineering studies, whereas little or none is required for STOP signs if conditions 1, 2, or 3 of the STOP warrant are used;
2. The belief by engineers that a single ultimate policy of stop control prepares them for all eventualities against tort liability; and
3. Political pressure from citizen groups in the mistaken belief that STOP signs offer greater protection than YIELD signs.

RELATIVE EFFICIENCY

Total road user cost per cycle was estimated from

Figure 1. Costs per cycle of stop and yield control.



more than 3000 observations at both stop- and yield-controlled intersections. This cost included both the vehicle operating cost and the delay cost, and was based on entry speed and travel time through the intersection. Figure 1 shows the cost differentials for major roadway volumes above and below 2000 vehicles/day (the point of significant difference in driver behavior). Yield control offers a 7.8 percent reduction in total cost below 2000 vehicles/day, and a 7.6 percent reduction at the higher volume level.

SUMMARY

Traffic control is highly visible and sensitive to public scrutiny. Understandably, the traffic engineer must consider and accommodate all drivers--the novice and the experienced, the familiar and unfamiliar, the defensive and aggressive. The task is not an easy one. The ultimate measure of successful traffic control is a good safety record. This can only happen through public understanding and acceptance of control devices. Many of the STOP signs at low-volume intersections are unjustified (although warranted by MUTCD) and could be replaced by YIELD signs without increasing accident experience. Furthermore, the use of YIELD signs would restore respect and effectiveness of the STOP sign and improve operating efficiency. The path of least resistance of a single policy of STOP control is contraindicated by the low rate of obedience to the STOP signs. Our findings are summarized below:

1. The low rate of driver compliance to the STOP sign is a result of its excessive use at intersections where it is not reasonable and necessary that all motorists stop,
2. There is no relation between major road traffic volume (up to 6000 ADT) and accident experience at low-volume intersections,
3. STOP signs do not reduce accident experience at low-volume intersections,
4. The supposition that STOP signs are being used at locations with poor sight distance as defined by AASHTO is not supported by data, and
5. STOP signs result in a higher road user cost than do YIELD signs.

In keeping with the philosophy that the least-restrictive device consistent with safety and smooth traffic flow should be used, the basic question is asked: When should the STOP sign be used? The answer may not be so easy.

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