SAFETY EFFECTS OF FLUORESCENT YELLOW WARNING SIGNS AT HAZARDOUS SITES IN DAYLIGHT

TRB Paper No: 01-2236

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July 2000

Word count: 5968 text + 1250 tables = 7,218 total

Key words: sign, warning, yellow, fluorescent, safety, collision, hazard

ABSTRACT

Yellow warning signs are an important and abundant type of traffic control device. Improving warning signs could be a cost-effective countermeasure at hazardous locations. The use of fluorescent yellow sheeting in place of standard yellow sheeting provides an inexpensive method to increase the conspicuity of the traffic sign while conforming to the guidelines specified by *the Manual of Uniform Traffic Control Devices*. Although the properties of the fluorescent yellow sheeting indicate that the conspicuity of the signs is much higher than standard yellow, the increased conspicuity ultimately must prompt a change in motorist behavior for highway safety to be improved. Therefore, the purpose was this research was to evaluate the effectiveness of fluorescent yellow warning signs in improving highway safety at hazardous locations. A before and after study used surrogate measures (encroachments, conflicts and events, signal violations, stop sign observance, stopping behavior, and speed) to evaluate the safety effectiveness of replacing existing yellow warning signs with fluorescent yellow warning signs at seven hazardous locations. The results of this effort indicate that fluorescent yellow warning signs likely increased safety at four of the seven sites by providing a more conspicuous warning to motorists, with little change at the other three sites. However, since surrogate measures were used, the actual collision savings are unknown. The researchers recommend use of fluorescent yellow warning signs as an inexpensive countermeasure at sites like those tested in the study, and also recommend more research to find the collision savings and long-term effects.

INTRODUCTION

The Problem

Yellow warning signs are an important and abundant type of traffic control device. Yellow warning signs inform the motorist about potentially hazardous conditions on, or adjacent to, a highway. Yellow warning signs may prompt a driver to become more alert, exercise more caution, or reduce speed. Yellow warning signs are commonly used prior to changes in alignment, changes in cross section, intersections, signals, or STOP signs. Because they are relatively inexpensive, many engineers believe that installing warning signs is generally one of the most cost-effective safety countermeasures available (*1*). The benefit to cost ratio of installing traffic signs as a safety countermeasure has been reported by the USDOT as 20.9 to 1 (*2*).

However, as with all signs, for yellow warning signs to be effective the driver must detect them and obtain the information on them. The conspicuity of a traffic sign is the key to its detection. If a motorist fails to detect a warning sign, the consequences could be severe. Exposure time is limited in the roadway environment by vehicle speeds. As the visual clutter increases along roadsides, the importance of traffic sign conspicuity also increases.

Engineers have tried various methods to make yellow warning signs more conspicuous. One method is the addition of fluorescent orange flags to the top of the sign. Although this may increase the conspicuity of the sign, it does not increase the conspicuity of the message that the sign is conveying. Additionally, the *Manual of Uniform Traffic Control Devices (MUTCD)* reserves orange for work zone signing *(3)*. Orange flags also tend to fade quickly in the weather. Some engineers have replaced the cloth flags with small square pieces of orange sheeting.

However, the orange and yellow colors together still send a mixed message, and the effective shape of the sign has been changed from that required by the *MUTCD*. Oversized signs have been used where greater legibility or emphasis is needed. However, fabricating larger signs increases the costs. A hazard identification beacon may also be used to supplement a warning sign, but the beacon greatly increases the cost of the device. Some have found beacons effective at reducing speeds in school zones *(4, 5)*. However, Hall studied the effectiveness of beacons at hazardous location on rural highways in New Mexico, and recommended judicious use of hazard identification beacons at those sites that cannot be sufficiently improved using more traditional forms of passive corrective action *(6)*.

Fluorescent Yellow Sheeting

Fluorescent yellow sheeting provides a relatively inexpensive method to increase the conspicuity of a traffic sign while conforming to the *MUTCD*. Fluorescent sheeting is different from ordinary sheeting because it absorbs short wavelength solar energy and then re-emits the energy as longer wavelength visible light. This increases the luminance of the sign. The increased luminance in turn provides a greater contrast against the surroundings and hence, a more conspicuous sign *(7)*.

In the past, rapid degradation prevented the use of fluorescence in long-term signing applications. Recently, though, a new class of long-lasting sheeting was developed that combines prismatic retroreflective optics with fluorescence. The resulting signs have a high level of nighttime retroreflectivity and an increased level of daytime luminance. Fluorescent orange sheeting is currently used by many jurisdictions for work zone signing. Fluorescent-yellow green has been accepted by the FHWA for use in pedestrian, bicycle, and school zone applications and many agencies are now using that sheeting. Yellow is the most recent fluorescent sheeting to be introduced.

ASTM D4956 *(8)* defines the yellow to be used for retroreflective traffic sign sheeting by the following chromaticity coordinates: (0.498, 0.412), (0.557, 0.442), (0.479, 0.520), and (0.438, 0.472). These are laboratory values under defined levels of lighting. The fluorescent yellow prismatic sheeting used in this research falls within these limits and thus may be used by agencies in place of nonfluorescent (i.e., standard) yellow sheeting without special permission from FHWA. (Request II-363 (Intr)-Fluorescent Yellow Sheeting on Warning Signs", FHWA HOTO, USDOT, May 27, 1999.)

Potential Safety Benefits

Although less expensive than oversized signs or beacons, fluorescent yellow sheeting currently costs approximately 15% more than comparable standard yellow sheeting. Some safety benefit for the driving public must be identified before many highway agencies will make the investment.

The literature provides some evidence of the promise of fluorescent yellow signs, but the effect of a fluorescent yellow warning sign on motorist behavior in a real traffic situation is still largely unknown. From tests of fluorescent yellow (and other color) sign sheeting in the laboratory and outdoors, Burns and Donahue *(9)* concluded that:

- laboratory and outdoor measurements of the colorimetric and photometric properties of fluorescent-retroreflective sheeting correlated well with each other;

- the nighttime photometric performance properties of fluorescent-retroreflective sheeting are similar to ordinary yellow sheeting of the same optical design; and
- yellow fluorescent-retroreflective prismatic material retains many of its original colorimetric and photometric properties after accelerated and natural weathering.

In another study, Burns and Johnson *(7)* compared the measured spectral radiance of fluorescent and non-fluorescent materials to the perceived visibility and conspicuity of the materials. They found a direct correlation between the perceived brightness of the targets and target luminance contrast, concluding that the photometric properties of fluorescent sheeting are the basis for their exceptional visibility and conspicuity. They also found that the luminance contrast of fluorescent targets increases significantly relative to non-fluorescent targets under heavily overcast and rainy conditions.

Jenssen et al. *(10)* evaluated the performance of fluorescent retroreflective signs on a closed course and on an open winding roadway in Norway. In the closed course, subjects seated in a moving railroad car indicated when they could detect and recognize the shape, color, and contents of fluorescent and non-fluorescent traffic signs (including yellow) as they approached. Participants detected fluorescent signs an average of 53 m sooner than their non-fluorescent counterparts during the day and an average of 31 m sooner at night. This significant difference was even larger within the 55-75 subject age group. On the roadway, the research team observed vehicle speeds and lane positions, conducted roadside interviews, and collected eye-scanning data from a small number of drivers. The signs were replaced in two phases. First, the existing encapsulated lens yellow sheeting chevrons were replaced with otherwise-identical fluorescent yellow and black prismatic signs. Second, all regulatory and warning signs, made of white enclosed lens sheeting, were replaced with fluorescent yellow-green signs. This was not only a change in fluorescence, but also a change in color. Jenssen et al. found a statistically significant reduction in light vehicle space mean speeds in both after periods (2.3 km/hr for phase 1, 4.1 km/h for phase 2). They also observed a reduction in centerline crossings on sharp left curves in the section.

De Vos, et al. *(11)* tested the effect of fluorescent yellow signing on driver behavior entering work zones (in the Netherlands, yellow signs apply to work zones). They videotaped the approach to a work zone on three consecutive days. Each day a different type of signing was installed on the approach: first non-fluorescent High Intensity Grade signing, then fluorescent signing, and finally fluorescent sheeting as a backing board behind a non-fluorescent High Intensity Grade sign. When fluorescent sheeting was in place, high speeds were reduced during dusk conditions. When the backing board was in place, the average speed and excessive speeds were reduced at the entry of the work zone during daytime and there was a decrease in potentially hazardous interactions between vehicles.

Purpose of Research

Given the promise of the fluorescent yellow warning sign as an inexpensive countermeasure and the fact that there has been little research to this point on its effects in the field, the purpose of this research was to evaluate the effectiveness of fluorescent yellow warning signs in improving highway safety at hazardous locations during daylight conditions. Using collision data, the researchers identified hazardous highway locations in Orange County, North Carolina and conducted a before-and-after safety evaluation of fluorescent yellow warning signs as a countermeasure. While the number of collisions or injuries saved is the ultimate measure of any countermeasure, a collision study would require a long time and many sites to conduct. Therefore, to obtain results quickly within the limited available resources, this research used the best available indirect safety measures to test the effectiveness of the fluorescent signs.

EXPERIMENTAL SITES

Site Selection

The researchers selected Orange County, North Carolina for the experiment based on cooperating officials, abundance of rural and secondary roads, moderate to heavy traffic volumes, rolling terrain, and the proximity to the researchers' offices.

The researchers began site selection by asking the North Carolina Department of Transportation (NCDOT) for a list of hazardous locations in Orange County based on collision history. The NCDOT provided a list of 55 locations. The researchers then visited each of the candidate sites and reviewed the 1996 through 1998 collision data for each site. The site selection criteria included:

- Presence of one or more yellow warning signs,
- Five or more reported collisions related to the hazard to which the sign referred during 1996-1998, and
- No ongoing construction.

After applying the criteria, only ten sites remained as candidates for the experiment. Preliminary data collection showed that traffic volumes were too low to collect meaningful samples of the desired measure of effectiveness at three of those sites. The experiment was conducted at the seven remaining sites.

Site Descriptions

This section includes brief descriptions of each of the seven sites used during the experiment. More details about the sites, including photos and sketches, and more details about many aspects of the research, are available in the research report (*12*).

Site A: Southbound NC-157 near Walker Road

NC-157 is a rural two-lane paved road with a reverse horizontal curve on a vertical crest. Southbound run-off-road collisions were the dominant collision type. Southbound, a driver would encounter a reverse curve sign (W1-4L) with a 35 mph auxiliary speed plaque and six chevrons. During the experiment the reverse curve sign and its auxiliary speed plaque were replaced.

Site B: Northbound NC-49 approaching NC-86

NC-49 ends at NC-86, intersecting at a very sharp (about 30-degree angle) stop controlled intersection. Approximately 300 m before the intersection, in the middle of a horizontal curve to the left, is a stop ahead sign (W3-1a), which was the only sign replaced during the experiment. At the intersection, NC-49 has stop signs on left and right sides of the northbound lane, with the left side stop sign positioned on a small concrete median. The majority of reported collisions at the intersection were due to northbound vehicles failing to observe the stop sign and striking vehicles on NC-86 or fixed objects off the roadway.

Site D1: Northbound and Southbound NC-86 at NC-57

NC-57 ends at a signalized intersection with NC-86. NC-86 is a north-south road. NC-57 is also a north-south road, but it curves to the west immediately before approaching the signal. There are signal ahead signs (W3-3) for northbound and southbound NC-86, both of which were replaced during the experiment. Most of the reported collisions were rear-end collisions, with a concentration of those on the northbound approach.

Site D2: Westbound NC-57 at NC-86

The same intersection described above as Site D1 also provided Site D2 with an emphasis on the westbound NC-57 approach to the intersection. The sharp curve to the right on westbound NC-57 and a small building on the corner block the view of the signal from the approach. On westbound NC-57 there is a signal ahead sign (W3-3), a right turn sign (W1-1R) with a 15 mph speed advisory plaque, and a large arrow sign (W1-6), all of which (except for the advisory speed plaque) were replaced during the experiment. Rear-end collisions were the main types of collision at the intersection.

Site F: Westbound Old NC-10 near SR-1723

There is a severe reverse curve on Old NC-10, first to the right then the left for the westbound driver. In the middle of the reverse curve is a small gravel road to the left and then a structure that carries a railroad over Old NC-10. On hundred and fifty meters prior to the beginning of the curve is a reverse turn sign (W1-3R) with a 25-mph speed advisory plaque. Five chevrons (W1-8) guide the westbound driver through the reverse curve, three for the first turn and two for the second. We replaced the reverse turn sign, the plaque, and all five chevrons during the experiment. A concentration of run-off-road collisions—several producing injuries—was recorded westbound on the reverse curve.

Site H: Northbound SR-1009 near Davis Road

SR-1009 is a paved, two-lane road with a posted 45-mph speed limit. A reverse curve—first to the right for northbound drivers-- begins about 120 meters north of the intersection of SR 1009 and Davis Road. There is a reverse curve ahead (W1-4R) sign on northbound SR-1009 9 meters south of Davis Road, which was replaced during the experiment. There are no chevrons in the reverse curve. A group of five run-off-road collisions were recorded for northbound vehicles in the reverse curve during 1996-1998.

Site I: Eastbound and Westbound SR-1777 near SR-1729

SR-1777 is a two-lane, paved road.. SR-1729 approaches from the north and ends at SR-1777. Southbound SR-1729 is stop-controlled while SR-1777 is uncontrolled. SR-1777 is in a sag vertical curve at the intersection. There are side road signs (W2-2) for eastbound and westbound SR-1777, both of which were replaced for the experiment. The majority of collisions were rear-end collisions involving eastbound vehicles.

EVALUATION METHODOLOGY

The objective of this section is to discuss the methodology that was employed in evaluating the fluorescent yellow warning signs.

Experiment Design

The researchers employed a simple before-and-after experiment to evaluate the effects of fluorescent yellow signs at hazardous sites. A before-and-after experiment is a paired comparison of measurements taken at the same location twice: once before a change and once after a change. A before-and-after experiment is an attractive experiment design because it allows a comparison to be made without having to consider variations between locations.

The *Manual of Transportation Engineering Studies (13)* identifies seven drawbacks to a before-and-after experiment design. The most serious of these drawbacks for this research were that other factors may cause the changes in the measure of effectiveness other than the treatment (history), and regression to the mean. Parker (*14*) recommended using a before-and-after with comparison site experimental design for field evaluations of fluorescent yellow green pedestrian signs due to concerns over history biases.

Fortunately, the experiment design overcame these biases. The researchers mitigated potential regression to the mean bias by using different measures to select study sites (collision frequency) and conduct the experiment (indirect measures). The short duration of this project (all data collection between mid-December, 1999 and mid-April, 2000) mitigated concerns about history biases. No major changes occurred during the project that would influence the results: no new traffic legislation was passed, no major road projects occurred near the experiment sites, seasonal variations were limited, and the sites had no noticeable changes in the driving environment. The relevant traffic volumes did not change significantly between the before and after periods at particular sites, and at most sites we were measuring free-flowing vehicles anyway. The research team made sure that light, pavement, and weather conditions were the same (daylight, dry pavement, and no rainy weather) during the before and after periods of data collection at particular sites. The researchers collected data from the same positions during each period. The researchers limited data collection to one data collector (Eccles) if possible--only one site needed the assistance of an additional data collector.

The treatment applied to the test units was a change in the color of the warning signs from yellow to fluorescent yellow. The new signs were identical in size and message to the existing signs. The fluorescent yellow signs were fabricated from a wide observation angle prismatic retroreflective sign sheeting by Corrections Enterprises, a division of the North Carolina prison system that is responsible for fabricating all signs used by the NCDOT. The existing yellow signs were primarily on Engineer Grade sheeting, with just a few signs on High Intensity Grade sheeting. However, the existing signs were relatively new and of high quality as the data below show (refer to Table 2).

At one site, the researchers provided a two-week warm-up period between the installation of the fluorescent signs and the beginning of the after period data collection. At the other six sites there was at least a three-week warm-up period. This allowed most of the novelty or surprise effects from the experimental signs to dissipate prior to data collection.

Measures of Effectiveness

The ultimate measure of effectiveness (MOE) for a countermeasure such as a yellow warning sign is the number of collisions it prevents. While an experiment that studies the collision effects of fluorescent yellow sheeting remains a great idea, the objective in this study was a quicker answer within limited resources. Therefore, during this research we used indirect measures or collision surrogates.

A single MOE could not be chosen to evaluate all sites. The warning signs at the sites convey different information to the drivers based on the type of hazard at each site. The MOE selected must be related to that information and hazard. The MOE selected at each location was therefore based on the collision history of the site, the traffic control devices at the site, the available staff and equipment resources, and the available observation locations.

Because run-off-road collisions were predominant and good vantage points hidden from motorists' views were available, the researchers selected centerline and edgeline encroachments in the curve as the MOE at Sites A and F. Hostetter and Lunenfeld *(15)* identify encroachments as a possible MOE when evaluating a horizontal curve and many researchers have used the measure. An encroachment occurs when a wheel touches or goes across a centerline or edgeline. Vehicles were coded into one of five possible categories: stayed in lane, minor white edgeline encroachment, major white edgeline encroachment, minor yellow centerline encroachment, or major yellow centerline encroachment. A minor encroachment was coded if all or part of the vehicle's tire drove on the edgeline or centerline. A major encroachment was recorded if the vehicle's entire tire went beyond the edgeline or centerline and was completely on the shoulder or in the opposing lane, respectively.

The researchers measured stop sign observance and the distance from the stop sign at which the brake light appeared at Site B. The only warning sign at Site B is a stop ahead sign, and the majority of collisions that occurred at this intersection involved vehicles failing to observe the stop sign. If a driver failed to see the stop ahead sign but did see the stop sign, the driver would have less reaction time to apply the brakes to slow her vehicle and observe the stop sign.

Stop sign observance was evaluated in accordance with accepted procedures *(13).* For brake light applications, the observer was positioned 120 meters in advance of the stop sign. Small orange flags, similar to the flags used to mark the underground utilities, were used by the observer to measure the distance from the stop sign where the motorists applied their brakes. Observations were coded into four categories: under 90 m, 90-115 m, over 115, and indeterminate. Vehicles were coded as indeterminate if the observer was unable to discern when the brakes were first applied because of glare from the sun or dirt covering the vehicle's brake lights. Platooned vehicles were excluded from data collection. If a queue was present at the stop sign, all vehicles approaching the stop were also excluded because the presence of the queue provided the motorist with information in addition to the yellow warning sign and the stop sign.

At Site D1, based on the presence of a traffic signal and the types of collisions occurring there, the researchers selected traffic conflicts and other unusual traffic events (primarily red light violations and emergency decelerations) as the MOEs. Change in the number of red light violations is an obvious measure of the effect of a signal ahead sign *(15).* Traffic conflicts are interactions in which one or more vehicles or road users take evasive action to avoid a collision with another vehicle or road user. Traffic conflicts are an accepted supplement to collision data in quickly estimating the hazardousness of an intersection (*13*). Migletz, et al. *(16)* studied the relationship between traffic conflicts and collisions and concluded that traffic conflicts of certain types are good surrogates for collisions at signalized intersections. The researchers collected traffic volume in conjunction with conflicts and events to provide a comparative measure of exposure.

The researchers choose vehicle speed approaching the hazard as the MOE at the remaining sites (D2, H, and I) and as a supplemental MOE for site F. Hostetter and Lunenfeld

(*15*) identified spot speeds as valid measures of effectiveness for evaluating horizontal curves such as at site D2, F, and H. The choice of speed as MOE also follows previous researchers such as Shinar et al. *(17)* and Lyles (*18*) who used speed to evaluate the effects of curve warning signs.

The researchers originally chose conflicts as the MOE at Site I. However, low traffic volumes meant that collecting a sufficiently large sample would have taken too much time. The researchers then instead collected speeds of vehicles approaching the unsignalized intersection as the MOE. This measure has some validity, as the predominant collision type was the rear-end collision, but this measure on an uncontrolled intersection approach is not as strong as the other MOEs used in the experiment.

Only free-flowing vehicles were targeted for speed data collection. Speeds were recorded from the same location each time at each site. Speed measurements were collected using a radar gun that was calibrated before each hour of data collection began.

After a thorough review of the literature, the recent TRB special report *Managing Speed (19)* concluded that both high mean speed and speed dispersion are associated with crash involvement. Based on this conclusion, the researchers analyzed both mean speed and the standard deviation about that mean.

Sample Sizes

The sample size collected at each site varied by MOE and the time needed to collect the data. Table 1 shows that approximately the same size of sample was collected in the after period as was collected in the before period.

TABLE 1 MOEs and Sample Sizes at Each Site

		Before period		After period	
Site	Measure of effectiveness	Hours of data collection	Sample size	Hours of data collection	Sample size
A	Centerline and edgeline encroachment	3	144 vehs.	4	202 vehs.
B	Stop sign observance	6	123 vehs.	7	143 vehs.
	Brake light distance		150 vehs.		175 vehs.
D1	Conflicts	10.5	12 confl.	11	8 confl.
	Events		14 events		6 events
D2	Speed	4	135 vehs.	5	123 vehs.
F	Centerline and edgeline encroachment	4	86 vehs.	3	88 vehs.
	Speed	4	111 vehs.	3.5	115 vehs.
H	Speed	3	83 vehs.	3	83 vehs.
I (EB)	Speed	1.5	60 vehs.	1.5	60 vehs.
I (WB)	Speed	1.5	63 vehs.	1.5	63 vehs.

Spectrometry Measurements of Existing Signs

To judge the quality of the existing signs, the researchers measured the luminance and chromaticity of a sample of the signs. Daytime luminance and chromaticity measurements were made in the field using a calibrated telespectroradiameter. We also made retroreflectivity measurements using a portable retroreflectometer. Complete details are available from the research report (*12*).

The field readings are relative to the ambient light at the time of the measurement. Therefore, when the existing yellow signs were measured, the researchers brought along a small fluorescent yellow sign from which to take comparative measurements. In the field, the researchers first collected the luminance, and chromaticity of the existing signs, then placed the fluorescent yellow sign next to the existing sign and collected its luminance and chromaticity under the same lighting conditions.

Table 2 displays the installation date, luminance measurement, and chromaticity measurement for a representative sample of signs at each site. Table 2 shows that the existing signs at the experiment sites were relatively new and in good condition. The data show the daytime luminance of the fluorescent yellow sign was a great deal higher than the existing ordinary yellow signs – on average 50% higher than the existing Engineering Grade signs. All the yellow backgrounds were clearly identifiable as yellow and plotted generally within the allowable ASTM yellow chromaticity range.

RESULTS

The results from the before and after experiment on the seven sites are presented in three tables. Table 3 presents encroachment, stop sign observance, brake light distance, and conflict and event results from sites A, B, D1 and F. These data were all reduced to proportions and analyzed with one-tailed Z-tests for proportions. Table 4 presents speed results from sites D2, F, H and I. The researchers analyzed these data with one-tailed t-tests of the mean values and percentiles and with one-tailed F-tests of the standard deviations. Finally, Table 5 imparts a summary of the statistical tests of all data and the conclusions the researchers drew from those test results. Readers should keep in mind while viewing Table 5 that a statistically significant change does not necessarily mean that there was a practical impact on traffic safety at the site.

TABLE 2 Sign Installation, Daytime Luminance and Chromaticity, and Retroreflectance Measurements Collected in the Before Period

Site	Sign	Material	Installation	Existing Yellow R_A	Existing Yellow Daytime Luminance	Existing Yellow Chromaticity		Fluorescent Yellow R_A	Fluorescent Yellow Daytime Luminance	Fluorescent Yellow Chromaticity		Relative Daytime Luminance
				cd/lux/m^2	cd/m^2	x	y	cd/lux/m^2	cd/m^2	x	y	Fluor Yellow/ Existing Yellow
A	Curve Ahead	Engineering	Jan. 98	63	1027	0.462	0.426	278	1353	0.536	0.443	1.3
	Speed template	Engineering	Jan. 98	60	939	0.476	0.438					1.4
B	Stop Ahead	Engineering	Not dated	55	621	0.450	0.441	278	1078	0.520	0.462	1.7
D1	Signal Ahead	Engineering	Feb. 97	49	11,000	0.481	0.451	278	Overload			--
D2	Signal Ahead	Engineering	Feb. 97	48	1399	0.454	0.422	278	2285	0.514	0.432	1.6
F	Curve Ahead	Engineering	Oct.95	70	5969	0.464	0.453	278	9806	0.532	0.458	1.6
	Speed template	Engineering	Oct. 95	60	6344	0.503	0.463					1.5
	Chevron 1	High Intensity	Mar. 98	245	2619	0.528	0.457	278	7992	0.535	0.459	3.1
H	Curve Ahead	Engineering	Oct. 95	60	6511	0.493	0.460	278	9524	0.529	0.458	1.5
I	Intersection Ahead	Engineering	Oct. 95	45	810	0.508	0.442	278	1323	0.540	0.436	1.6

TABLE 3 Encroachment, Stopping, and Conflict Results

Site	MOE	Category	Before period		After period	
			Amount	Percent of total	Amount	Percent of total
A	Encroachments	Stayed in lane	90	63.8	134	66.3
		Minor yellow	4	2.8	8	4
		Major yellow	0	0	0	0
		Minor white	42	29.8	54	26.7
		Major white	5	3.5	6	3
		Total	141	100	202	100
B	Stop sign observance	Voluntary full stop	78	63.4	92	64.3
		Practically stopped	30	24.4	46	32.2
		Non-stopping	15	12.2	5	3.5
		Total	123	100	143	100
	Brake light distance	Over 115 m	65	43.3	92	52.6
		90-115 m	60	40	65	37.1
		Under 90 m	25	16.7	18	10.3
		Total	150	100	175	100
D1	Conflicts	Yes	12	0.3	8	0.2
		No	4035	99.7	4525	99.8
		Total	4047	100	4533	100
	Events	Ran red signal	10	0.2	5	0.1
		Quick deceleration	4	0.1	1	0
		None	4033	99.7	4527	99.9
		Total	4047	100	4533	100
F	Encroachments	Stayed in lane	64	57.7	78	67.8
		Minor yellow	9	8.1	1	0.9
		Major yellow	1	0.9	0	0
		Minor white	35	31.5	34	29.6
		Major white	2	1.8	2	1.7
		Total	111	100	115	100

TABLE 4 Speed Results

Site	Parameter	Before period, km/h	After period, km/h
D2	Mean	68.6	66.3
	Standard deviation	7.7	8.9
	50th percentile	69.2	67.6
	85th percentile	75.6	74.0
F	Mean	58.9	55.7
	Standard deviation	6.4	7.1
	50th percentile	57.9	54.7
	85th percentile	66.0	62.8
H	Mean	79.2	78.7
	Standard deviation	6.4	6.3
	50th percentile	78.9	78.9
	85th percentile	85.3	85.3
I (EB)	Mean	76.6	73.4
	Standard deviation	8.9	7.1
	50th percentile	77.2	72.4
	85th percentile	85.3	80.5
I (WB)	Mean	74.5	73.7
	Standard deviation	7.2	6.6
	50th percentile	74.0	74.0
	85th percentile	82.1	80.5

Conversion: 1 km/h=0.62 mph

TABLE 5 Summary of Statistical Tests

Site	MOE	Change from before to after	Significance	Reflect a probable increase in safety?
A	Centerline and Edgeline Encroachments	2.5% increase in the amount that maintained lane	Not at 90%	No
		3.6% decrease in the amount that encroached on the white edgeline	Not at 90%	
B	Stop Sign Observance	0.9% increase in the amount of voluntary full stops	Not at 90%	Yes
		8.7% decrease in amount of non-stopping vehicles	Yes, at 99%	
	Stopping Distance	9.3% increase in amount that began stopping at greatest distance	Yes, at 95%	
		6.4% decrease in amount that began stopping at least distance	Yes, at 95%	
D1	Traffic Conflicts	Decreased from 12 conflicts to 8	Not at 90%	Possibly, Yes
	Traffic Events	Decreased from 14 events to 6	Yes, at 95%	
D2	Speeds approaching intersection	Mean speed decreased by 2.3 k.p.h	Yes, at 95%	No
		1.6 kph decrease in 50th and 85th percentile speed	Yes, at 90%	
		Standard dev. increased by 1.1 kph	Yes, at 90%	
F	Centerline and Edgeline Encroachments	10.1% increase in the amount of vehicles that maintained lane	Yes, at 90%	Yes
		5.1% decrease in the amount that encroached on the white edgeline	Not at 90%	
		12.2% decrease in the amount that encroached on the yellow centerline	Yes, at 99%	
	Speeds approaching curve	3.2 k.p.h decrease in mean, 50th, and 85th percentile speed	Yes, at 99%	
		Standard dev. increased by 0.6 k.p.h.	Not at 90%	
H	Speeds approaching curve	Mean speed decreased by 0.5 k.p.h	Not at 90%	No
		Standard dev. decreased by 0.2 kph	Not at 90%	
I	Speeds approaching intersection EB	3.2 kph. decrease in mean speed	Yes, at 95%	Possibly, yes (EB)
		5 kph decrease in 50th %tile	Yes, at 99%	
		5 kph decrease in 85th %tile	Yes, at 99%	
		Standard dev. decreased by 1.8 kph	Yes, at 95%	
	Speeds approaching intersection WB	0.8 kph decrease in mean speed	Not at 90%	No (WB)
		1.6 kph decrease in 85th %tile	Not at 90%	
		Standard dev. decreased by 1.6 kph	Not at 90%	

Conversion: 1 km/h=0.62 mph

Tables 3, 4 and 5 show that the installation of fluorescent yellow warning signs appeared to increase safety at some hazardous sites in this study. One striking finding from the experiment is that *all MOEs except two improved in the after period.* The standard deviations of speed at sites D2 and F were the only two MOEs that changed negatively in the after period, and of these only the change at D2 was significant at the 90 percent level. Many of the improvements were statistically significant at the 90, 95, or 99 percent level. The improvements in stop sign observance and brake light distance at Site B and in vehicles staying in lanes at Site F are especially striking, as those are strong MOEs. The decline in red light violations at Site D1 is also important. In all, the improvements at Sites B, D1, F, and I (eastbound) are large enough and or in strong enough MOEs that it is likely that those sites would have small long-term reductions in their collision frequencies.

Fluorescent yellow appeared to be most effective at the experiment sites where the warning signs provide advance information that is not reiterated by other features. For instance, at site B, the warning signs inform the motorist they are approaching a stop sign. Due to the geometry of the location, the stop sign itself is not visible until approximately 100 meters beyond the warning sign. The warning sign provides information vital to the motorist so that he or she can prepare for the stop sign. Similar geometry limitations are present at Site D1, Site D2, and Site F. At Site D1, the view of the traffic signal can be obstructed by a combination of the geometry and other vehicles. At Site D2, the view of the traffic signal is obstructed by a building until almost immediately before the intersection. At Site F, the surrounding environment masks the severity of the curve. At Site B, Site D1, and Site F, the changes attributable to fluorescent yellow signs are strong enough that they likely increased safety. At Site D2 although the mean, 50th percentile, and 85th percentile speeds were significantly decreased, the standard deviation about the mean speed was significantly increased, so the fluorescent yellow signs likely did not materially increase safety at this site. By contrast, at Sites A and H the warning signs provide redundant information (the curves were more visible and there were chevrons at Site A) and the fluorescent yellow signs probably did not improve safety much at those sites.

RECOMMENDATIONS

Based on the results, the researchers provide three categories of recommendations: for use of fluorescent yellow sign sheeting, for similar studies, and for future research.

Recommendations for Use

The researchers recommend fluorescent yellow warning signs as an inexpensive safety countermeasure where more driver attention to a hazard is needed. At sites like those examined in this study, use of fluorescent instead of standard yellow sheeting in warning signs will likely prevent a few collisions over the long term. Fluorescent yellow sheeting appears most beneficial where the roadway geometry or obstructions hide the hazard for which the sign is providing the only warning. No traffic control device can substitute for removing the hazard, of course.

Although the yellow fluorescent retroreflective sheeting used in this study costs approximately fifteen percent more than standard yellow sheeting with the same retroreflective optics ($5.44 per square foot as opposed to $4.72 per square foot in April 2000), over the lifetime of the sign the extra cost is not significant compared to the costs of other countermeasures. The estimated cost of installing a 36” standard yellow sign in North Carolina is currently $161. The estimated cost of installing a 36” fluorescent yellow warning sign is $178. Sheeting costs are lower for a standard size (36”) fluorescent yellow sign than for an oversize (42”) standard yellow warning sign ($49 to $58). A fluorescent yellow sign is also far less expensive than installing and maintaining a flashing beacon above the sign.

Fluorescent yellow sheeting appears to provide a low cost method to increase the safety of hazardous sites like those tested by increasing the conspicuity of the warning sign. However, the findings of this study are limited to only seven experimental sites in a single North Carolina county. More research is suggested before wider application of fluorescent yellow sheeting is recommended or before agencies should consider requiring fluorescent yellow sheeting.

Recommendations for Similar Studies

The researchers intended to randomly select the experimental sites from a list of candidates. Although the list of locations received from the NCDOT had fifty-five locations on it, all but seven had to be excluded based on the site selection criteria. Although at the time the request was made fifty-five sites seemed large enough, a larger list of locations should be requested for similar studies in the future.

Recommendations for Future Research

The ultimate measure of effectiveness of a yellow warning sign is the number of collisions it prevents. The indirect measures employed for this study support the hypothesis that fluorescent yellow warning signs increase safety at hazardous locations like those tested. However, relating changes in the indirect measures to actual collision savings is difficult. A collision study would not only help to corroborate the findings of this study, but would also help quantify the collision savings. Additionally, the long-term effects of fluorescent yellow sheeting remain unknown. A large-scale collision study could also determine if certain types of signs provide more collision savings when changed to fluorescent than others.

A collision study of fluorescent yellow signs would also help show the magnitude of collision savings a sign improvement could produce in general. Distressingly few collision studies of signs are available in the literature—most studies have used indirect measures. Engineers comparing the safety effects of sign countermeasures to the safety effects of other types of countermeasures are usually forced to compare “apples to oranges” (collision results to indirect measure results). Yellow warning signs are abundant, permanent, and (often) placed at hazardous sites, making them great candidates for learning about the effects of signs on collisions in general.

ACKNOWLEDGEMENTS

The research was supported by the Southeastern Transportation Center, which is in turn supported by the USDOT University Transportation Centers Program, and North Carolina State University. The 3M Company provided fluorescent yellow sheeting for the new signs, Corrections Enterprises fabricated the new signs, and the NCDOT provided the sites and the crews to install the new signs. The authors are grateful to all of these entities for their support. The authors wish to thank particularly Mr. David Burns and Mr. Tim Inglis of 3M; Mr. Chuck Congleton of Corrections Enterprises; and Mr. John Permar, Mr. Scott Collier, and Mr. Mike Stout of the NCDOT.

The views and opinions expressed in this paper are those of the authors and do not necessarily reflect the views and opinions of any of the entities named above. The authors assume full responsibility for the accuracy of the data and conclusions presented in this paper.

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