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Relationship of the Color of the Highway Centerline Stripe to the Accident Rate in Arizona

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The problem considered in this study was that of the effect of changing the color of the centerline stripe from white to yellow on the accident rate on undivided, two-lane, two-way highways in Arizona. Only sections of roadway that had remained essentially unchanged (except for the color of the centerline stripe) for a period of 1 year before and 1 year after the color change were studied. Accident data on 74 sections of roadway, totaling 4587 km (2867 miles), were analyzed and statistically tested for differences between the accident rate with white centerlines and the accident rate with yellow centerlines under various road surface and light conditions. Of the eight accident-rate categories tested, the following four showed a significant increase: (a) the dawn or dusk accident rate, (b) the dawn or dusk accident rate during periods of wet pavement or poor visibility, (c) the nighttime accident rate during periods of wet pavement or poor visibility, and (d) the overall accident rate during periods of wet pavement or poor visibility. The following other four categories tested showed no significant change: (a) the nighttime accident rate, (b) the daytime accident rate, (c) the daytime accident rate during periods of wet pavement or poor visibility, and (d) the overall accident rate under all conditions combined. These data indicate that the currently used yellow centerline stripes are inferior to the previously employed white centerline stripes.

The most recent edition of the Manual on Uniform Traffic Control Devices, published in 1971, requires that all centerline markings on two-lane, two-way highways be yellow rather than the white previously in use. The expressed intent of this requirement is to further a new concept whereby the color difference between the markings of two-way and divided highways enables the motorist to be immediately aware of the danger of opposing traffic on seeing a yellow line. The lane markings remain white to eliminate any possible confusion.

The new centerline standard has an easily perceived safety objective. There can be no argument with its purpose; however, the questions to be asked are (a) has the desired result been achieved and (b) have any adverse conditions been created?

Some officials of the Arizona Highway Department have voiced an unsubstantiated belief that yellow striping may not be as visible as white striping, particularly in bad weather and at night. The purpose of this study is to provide a statistical basis for accepting or rejecting this belief. If it is true, the striping color change should have led to a higher accident rate.

The problem considered, then, is that of the relationship between the change of the color of the centerline stripe from white to yellow and the accident rate on undivided, two-lane, two-way highways in Arizona. Implied within this statement are the following subfactors that should be considered in evaluating the overall problem:

1. Did the dawn or dusk accident rate change significantly?
2. Did the nighttime accident rate change significantly?
3. Did the daytime accident rate change significantly?
4. Did the rate of accidents attributed to wet pavement or to poor visibility caused by bad weather conditions change significantly?
5. Did the overall accident rate change significantly?

HYPOTHESES EVALUATED

The following null hypotheses, based on the above subfactors, were tested:

1. The dawn or dusk accident rate before the color of the centerline stripe was changed is less than or equal to the dawn or dusk accident rate after the color was changed.
2. The nighttime accident rate before the color of the centerline stripe was changed is less than or equal to the nighttime accident rate after the color was changed.
3. The daytime accident rate before the color of the centerline stripe was changed is less than or equal to the daytime accident rate after the color was changed.
4. The rate of accidents attributed to wet pavement or to poor visibility caused by weather before the color of the centerline stripe was changed is less than or equal to the rate of accidents attributed to wet pavement or to poor visibility caused by weather after the color was changed.
5. The overall accident rate before the color of the centerline stripe was changed is less than or equal to the overall accident rate after the color was changed.

SCOPE AND LIMITATIONS

This study covers only undivided, two-lane, two-way highways of the Arizona State Highway System. The study was confined to the 12 months before and the 12 months after the striping change was accomplished. To eliminate the possible effects of the 1973 fuel shortage and the lowering of the maximum speed limit to 88.5 km (55 mph) in 1974, statistics on accidents and traffic volumes observed after September 30, 1973, were not considered. The reduction in vehicular travel due to the fuel shortage was first noticeable in October 1973 (1). An adequate sample size was provided by the use of the 24-month period of accident data.

Any portions of a highway undergoing changes in configuration other than changing the color of the centerline stripe—such as widening the shoulders, changing the roadway width, or adding lanes—during the time of the study were not included.

The validity of the findings in this study are limited by the accuracy of the data supplied by the various state agencies. Errors in accident data can result from the fact that the investigating police officer often must use judgment in filling out the accident report.

Many statistics and other information of interest to the traffic engineer are based on the unsubstantiated statements of accident victims or the value judgments and recollections of the investigating officer. Nevertheless, the shortcomings associated with accident reports should not discredit them as a useful research tool. The errors in the reports can be expected to be consistent from year to year, thus permitting reasonably accurate comparisons between years.

REVIEW OF RELATED RESEARCH AND LITERATURE

Many articles and studies concerning accidents and accident rates as related to traffic volumes, elements of the roadway cross section, lane lines, roadside obstructions, and roadway surface were reviewed. The findings and comments from a few of these are given below. (The Arizona Department of Transportation computer input to the Transportation Research Information Service failed to find any literature relating accidents to the centerline stripe.)

However, Stieg (2) has made the following comment on the visibility of white versus yellow centerlines:

> The yellow traffic line has an unfortunate tendency to disappear just when it is needed most.
>
> The specified yellow color is generally believed to be highly visible, a belief that appears to have been substantiated by Air Force research which placed this color high on its list of those that provide easy recognition in the air for flying aircraft, and high visibility on the ground for downed fliers. These findings, however, are related to chromatic contrast against blue sky and green grass or other vegetation, in bright sunlight. These are definitely not the conditions that prevail on our highways during the dusk-to-dawn period of highest fatal accident density. . . .
>
> The increased use of yellow markings on our highways has not taken into consideration the very real deficiencies of standard highway yellow as a visible warning device.
>
> The normal human eye does not perceive the color as quickly as it does white because of its low reflectance, which derives from (a) low refractive index . . . . Furthermore, the normal dark-adapted human eye sees even less under critical twilight conditions.
>
> The abnormal human eye, due either to congenital defects, or to those imparted by disease or by the use of alcohol, tobacco or drugs, may not perceive yellow as a color at all.

The causes of accidents are many and varied. Johnson (3), reporting on the findings of a research team, stated, "Among the 68 subjects studied, 289 contributing factors were identified—an average of 4.3 factors/case." (A factor was defined as any circumstance connected with a traffic accident without which the accident could not have occurred.)

The vehicle driver is undoubtedly the most important single component of the driving process and also the most difficult to understand and control [Conger (4)]. Numerous studies have attempted to isolate the human traits that are apparent in individuals involved in accidents. Although certain psychological traits, such as aggressiveness, intolerance, and resentment of authority are apparent in chronic traffic violators and accident repeaters, one study concluded that it would be difficult if not impossible to use human characteristics as reliable predictors of accident involvement [Goldstein (5)].

The roadway has been shown to have little direct causal relationship to automobile accidents. Michaels (6) reported, "in only 5 percent of accidents do observable characteristics of the highway play a significant causal role." Although the direct causal relationship may be low, the roadway undoubtedly influences the accident rate because the highway can require mental and physical responses beyond the abilities of the driver. The best evidence of such influences is the low-accident rates on modern, well-designed, fully access-controlled highways as compared with the accident rates on older, less expensive roadways [Burch (7)].

The traditional method of measuring exposure to highway traffic accidents is vehicle distances driven. Stewart (8) wrote that the vehicle distance rate of exposure involves three assumptions: (a) all driving involves some exposure to accident hazards, (b) the exposure to accident hazards is proportional to the distance driven, and (c) the degree of exposure is the same for all drivers. Since vehicle distances are the unit of exposure used in this study, Stewart's assumptions are also used.

RESEARCH DESIGN

To obtain statistically accurate data for use in answering the questions, the research design was subdivided into five major areas: establishment of the time frame of the study, delineation of the study area, analysis of the accident data, derivation of the traffic volumes, and determination of the statistical methods to be used.

Establishing the Time Frame

The dates when the centerline colors were changed by the Arizona Highway Department on all state and U.S. routes were obtained from the Weekly Striping Reports of the Arizona Highway Department (9). While most routes were changed in the first 4 months of 1972, the entire system was not completely changed until August 1, 1972.

The time frames for the before-and-after accident data were that the before period would be all of 1971 and the after period would be from September 1, 1972, through August 31, 1973. The selection of these time periods permitted all roads to have yellow centerlines for at least 1 month before the accident data analysis for the after period. Terminating the after period on August 31, 1973, eliminated any effects that the program of edgelining two-lane roads might have had on the accident rate because this program was not begun until November 1973. This also eliminated any effects of the 1973 fuel shortage or the 1974 speed-limit reduction.

The study, then, covers 32 months: 12 months with white centerlines, 7 months changeover, 1 month to allow drivers to become accustomed to the yellow centerlines, and 12 months with yellow centerlines.

Delineating the Study Area

All roadway sections were eliminated from the study area that (a) had more than two lanes, (b) were divided, (c) were less than 8 km (5 miles) long, (d) went through major urban areas, or (e) had any configuration change other than that of the color of the centerline stripe.

Sections of roadway less than 8 km (5 miles) in length were eliminated because it was believed that there would be insufficient exposure and therefore a relatively small number of accidents. The section would then be insensitive to changes in the accident rate.

Urban sections of roadway were eliminated from the study area because (a) the responsibility for pavement striping varied from area to area, (b) the striping patterns often changed daily, and (c) the presence of many other variables would make it difficult to isolate the effect of the color of the centerline stripe.

The determination of the configuration changes that took place during the time frame of the study was accomplished with the assistance of the Arizona Department of Transportation and by examination of its Complete Project Numbering Reference. A letter was then sent to each of the seven Arizona Department of Transportation District Engineers to verify that the remaining sections of roadway had remained unchanged throughout the 32-month time period under investigation. Three additional sections of roadway were eliminated from the study area as a result of the responses received.

To preserve a meaningful sample size, no attempt was made to eliminate the numerous sections of roadway affected by the frequent alterations of passing zones.

After all of the criteria were applied to the two-lane, two-way routes in the Arizona State Highway System, 74 sections of roadway totaling 4587 km (2867 miles) remained to be studied. These sections represent approximately 74 percent of the total length of two-lane, two-way routes available in Arizona.

Each of the 74 sections was arbitrarily given a study-section number for ease in referencing.

Analyzing the Accident Data

Although an accident may have many contributing causal factors, traffic engineers generally agree that three classes of accidents—(a) head-on collisions, (b) sideswiping collisions, and (c) vehicles running off the roadway—can be reduced by the installation of pavement centerlines. Other factors can and do contribute to these accident types, but the pavement centerline is considered as a major contributory factor in only these three types of accidents (10). Thus, these types of accidents are considered as related accidents for the purpose of this study, and they were the only types used.

Accident data for the study area were obtained from the Arizona Department of Transportation for the before-and-after time periods. Over 5200 accident summaries were examined, categorized, and tabulated by study-section number, accident type, roadway-surface condition, and light condition at the time of the accident.

Accidents that involved hitting an animal or some mechanical failure of the vehicle were categorized separately. Accidents that occurred when it was snowing, raining, blowing dust, or when the pavement was wet were tabulated into a separate category entitled wet or poor visibility.

Deriving the Traffic Volumes

Traffic volumes in terms of the average daily traffic (ADT) were calculated from the data given by the Arizona Highway Department (11).

The before time period was all of calendar year 1971, and the calculations of ADT for the 74 sections came directly from the 1971 data. However, because the ADT counts ceased to be published on a monthly basis in 1971 and the after time period included the last 4 months of 1972 and the first 8 months of 1973, an estimate was made of the ADTs for that time period.

A check of monthly volumes as a percentage of yearly totals showed that the last 4 months of 1971 accounted for 31 percent of the total yearly volume, which agrees closely with the results of Burritt and Moghrabi for 1973. It was then assumed that the monthly traffic-volume percentages had remained fairly constant for the years 1971 through 1973, and the estimated ADT for the after time period was calculated by taking 31 percent of the 1972 traffic volume for each study section and adding to this 69 percent of the 1973 traffic volume for each study section.

The following calculation of the ADT study section 1, US-60 from milepost 30.00 to milepost 70.00 is typical. The traffic count data are available from the Log of the Arizona Highway System (12) as shown below (1 km = 0.62 mile).

Road Section	Length (km)	Annual Avg 24-h Traffic 1971	1972	1973
From I-10 to Ariz-72	29.18	6406	7084	3030
From Ariz-72 to Maricopa County Line	39.82	6662	7367	4070

In general, the ADTs are calculated as follows:

$$ADT = \Sigma(\text{road-section length})(\text{ADT for that road section})/\Sigma(\text{road-section length}) \quad (1)$$

For the before period, ADT = [(29.18 × 6404) + (39.82 × 6662)]/(29.18 + 39.82) = 6554 vehicles/d, and for the after period, ADT = (0.31 × 1972 ADT) + (0.69 ×1973 ADT); i.e., ADT = {0.31 [(29.18 ×7084) + (39.82 ×7367)]/(29.18 + 39.82)}+ {0.69 [(29.18 ×3030) + (39.82 × 4076)]/(29.18 + 39.82)} = 4751 vehicles/d.

STATISTICAL ANALYSES OF THE ACCIDENT RATES

The hypotheses to be tested were stated in a manner requiring a determination of whether the accident rate under various conditions changed significantly. It was necessary, therefore, to calculate several categories of accident rates for each of the 74 sections of roadway with the white centerlines in use and with the yellow centerlines in use.

Because the roadway sections comprising the sample were essentially identical except for the color of the centerline stripe, the statistical analysis required involves paired observations. If the difference between the sample variances is large or if it is otherwise unreasonable to treat the population variances as being equal, one method that can be used for significance testing is the paired-sample t-test. This test does not require an assumption of equal population variances; it applies two random samples of the same size, which need not be independent. When n pairs of such observations are selected from two nonnormal populations, for large n ($n > 30$), the distribution of the mean of the differences is approximately normal, and tests of hypotheses concerning the means may be carried out by using the statistic

$$T = (\overline{D} - d_0)(n)^{1/2}/S_d \quad (2)$$

where

$\overline{D}$ = mean of the differences of n pairs of observations,
d_0 = value to which the difference of the two sample means is being compared,
S_d = standard deviation of the differences of n pairs of observations,
n = number of paired observations in the sample, and
$\nu = n - 1$ = number of degrees of freedom.

There were 74 paired observations. By using a level of significance of 0.05, the critical region was found to be $T > t_{\alpha,\nu} t_{0.05,73} = 1.645$.

The table below shows the actual changes in the related accident rates for the conditions tested.

Condition	Change (no. of study sections) Decrease	None	Increase
Light			
Dawn or dusk	23	21	30
Nighttime	39	5	30
Daytime	38	2	34
Wet pavement or poor visibility			
Dawn or dusk	6	53	15
Nighttime	20	28	26
Daytime	25	26	23
Overall	23	17	34
Combined	34	2	38

Table 1 gives the magnitudes of the before-and-after rates, the differences, and the significances for all 74 sections of roadway.

Of the eight accident-rate categories tested, four showed no change in the accident rate with the yellow centerline stripes in use, and four showed an increased accident rate with the yellow centerline stripes in use. The four categories showing no change were the nighttime related accident rate, the daytime related accident rate, the daytime related accident rate during periods of wet pavement or poor visibility, and the overall related accident rate under all conditions combined. The four categories showing an increase were the dawn or dusk related accident rate, the dawn or dusk related accident rate during periods of wet pavement or poor visibility, the nighttime related accident rate during periods of wet pavement or poor visibility, and the overall related accident rate during periods of wet pavement or poor visibility.

CONCLUSIONS AND RECOMMENDATIONS FOR FURTHER RESEARCH

The results of the eight statistical tests performed do not provide a clear-cut answer to the relationship between the color of the centerline stripe and the accident rate in Arizona. In general, the data seem to indicate that the yellow markings have had a detrimental effect on the related accident rate. Four of the related-accident-rate tests showed no change, and four showed a significant increase in the related accident rate.

As work on this project progressed and conclusions were drawn, a number of questions were raised for which no answers were evident. Many of these questions could be solved only by additional, and often specific, studies that were beyond the scope of this project.

The following eight conclusions refer to the specifically named accident rate with yellow centerlines in use at the 5 percent level of significance:

1. The dawn or dusk accident rate increased significantly.
2. The dawn or dusk accident rate under conditions of wet pavement or poor visibility caused by bad weather increased significantly.
3. The nighttime accident rate under conditions of wet pavement or poor visibility caused by bad weather increased significantly.
4. The overall accident rate under conditions of wet pavement or poor visibility caused by bad weather increased significantly.
5. The nighttime accident rate showed no significant change.
6. The daytime accident rate showed no significant change.
7. The daytime accident rate under conditions of wet pavement or poor visibility caused by bad weather showed no significant change.
8. The overall accident rate under combined conditions of dawn or dusk, nighttime, daytime, and wet pavement or poor visibility caused by bad weather showed no significant change.

If a true evaluation of the white versus yellow centerline accident rate comparisons is to be made, it must be assumed that the proportions of the traffic volumes for each light condition to the ADT volumes remained fairly constant from year to year. Although no data are available on traffic volumes by time periods within a given day, it can be reasonably assumed that these proportions did in fact remain constant. The same assump-

Table 1. Average accident rates per hundred million vehicle miles.

Condition	Related Accident Rates			Significant at $\alpha = 0.05$
	White	Yellow	Difference	
Light				
Dawn or dusk	5.65	8.14	2.49	Yes
Nighttime	41.58	40.19	-1.39	No
Daytime	45.31	39.23	-6.08	No
Wet pavement or poor visibility				
Dawn or dusk	0.65	1.55	0.90	Yes
Nighttime	3.28	8.10	4.82	Yes
Daytime	8.13	8.00	-0.13	No
Overall	12.04	17.77	5.73	Yes
Combined	92.64	87.55	-5.09	No

Note: Discrepancies in totals are due to rounding of actual accident rates.

tion regarding the proportions of traffic volumes during periods of wet pavement or poor visibility caused by bad weather is not as easily made. Did the number of hours, or even days, when such weather conditions prevailed remain the same for the before and after time periods? Did the volumes of traffic using the roads under such conditions remain constant throughout the entire time period of the study? The data required to provide answers to these questions are not available. If the after time period contained many more days with conditions of wet pavement or poor visibility than did the before period, the increase in the dawn or dusk, nighttime, and overall accident rates (under conditions of wet pavement or poor visibility) stated previously in conclusions 2, 3, and 4 respectively cannot be attributed solely to the changed color of the centerline.

Even though this argument cannot be answered satisfactorily with the data available, the overall conclusion of this study is that the significant increases in the dawn or dusk accident rate, the dawn or dusk accident rate under conditions of wet pavement or poor visibility, the nighttime accident rate under conditions of wet pavement or poor visibility, and the overall accident rate under conditions of wet pavement or poor visibility indicate that the currently used yellow centerline stripe is inferior to the previously used white centerline stripe.

Most research to date on the relationship of accidents to traffic volume has dealt with all accidents and with total traffic. It would be much more useful to relate accident rates by time of day and hourly traffic volumes. Because accident summaries carry notations of the time of day and the day of year, they could be used directly to evaluate hourly, daily, and seasonal variations in rates. Continuous traffic-count stations are now in use, and a study could be initiated to explore the possibility of coordinating these continuous traffic counts with the time of accident so that accident rates could be calculated on an hourly basis. These data, then, would be valuable in evaluating specific situations and in determining the merit of specific improvements.

There is also a need for more comprehensive information in terms of increased weather-bureau data. If data relating the temperature and road conditions on specific sections of readway could be recorded for future use, accident rates for poor weather conditions could be made more meaningful.

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