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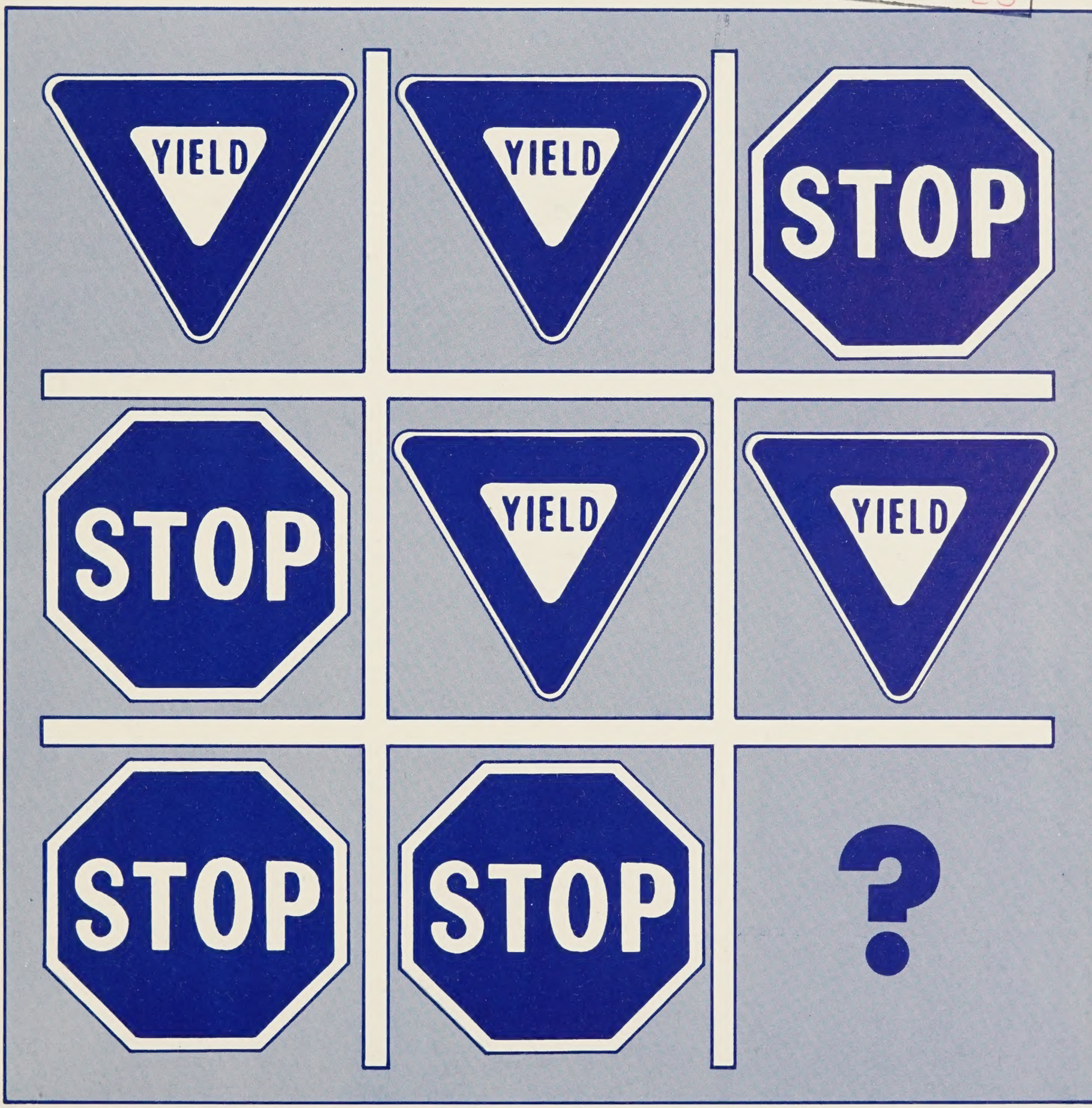

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COVER: Research continues on the safety effects of controlling traffic with STOP versus YIELD signs.

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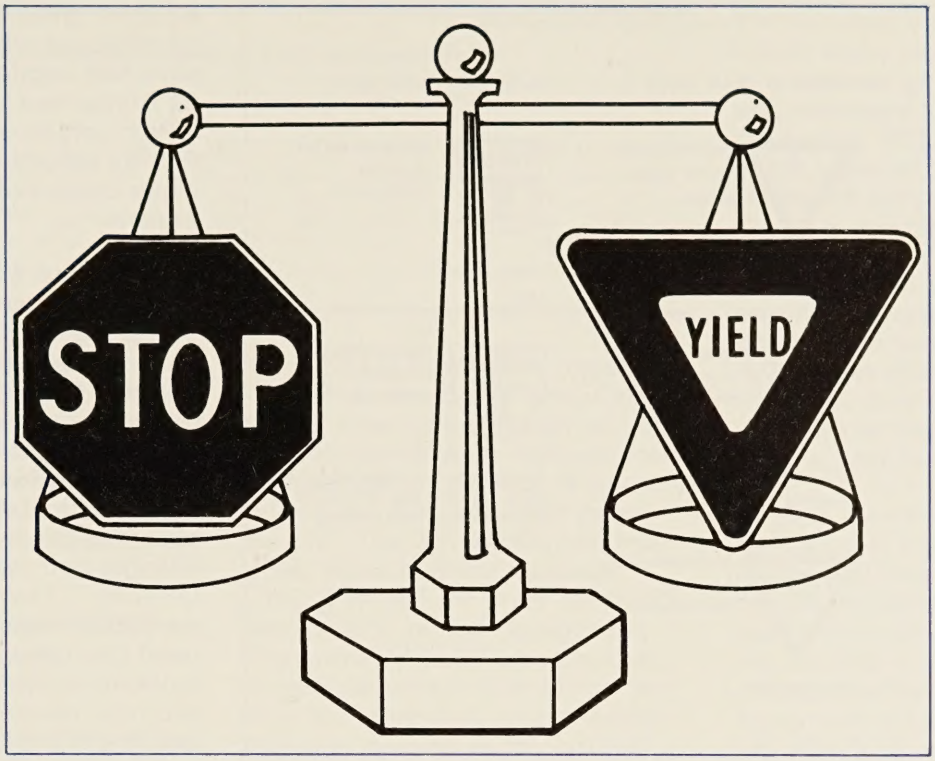

A Review of Research Related to the Safety of STOP Versus YIELD Sign Traffic Control

by
Merton J. Rosenbaum

Introduction

Since the 1920's, the STOP sign has been used for traffic control at many intersections where signals were not justified but traffic volumes and sight distances indicated the need for some kind of priority control. In 1951 the YIELD sign was introduced in Tulsa, Oklahoma, but still the STOP sign is used more frequently than the YIELD sign. Already well known is that replacing STOP signs with YIELD signs, where appropriate, can substantially reduce energy consumption, traffic delay, and air pollution. However, the consensus of the available, but limited, safety research does not clearly indicate the change in accident experience when replacing a STOP sign with a YIELD sign.

The National Committee on Uniform Traffic Control Devices has proposed a comprehensive nationwide study of the safety effects of replacing STOP signs with YIELD signs. If no significant change and/or increase in accidents exists, replacing appropriate STOP signs with YIELD signs could be justified from a safety point of view, encouraging traffic engineers and administrators to promote wider use of the more cost-effective YIELD sign. To provide background information in support of a nationwide study, this article reviews the accident experience since the YIELD sign was introduced.

STOP and YIELD Sign Development

Figure 1 traces the historical development of the STOP and YIELD signs. The design, criteria, and warrants for both signs have been revised in successive editions of the Manual on Uniform Traffic Control Devices for Streets and Highways (MUTCD) and its predecessors.

In January 1923 the Mississippi Valley Association of State Highway Departments adopted and passed on to the American Association of State Highway Officials (now the American Association of State Highway and Transportation Officials) recommendations that formed the basis for national standards in the 1927 manual and specification for U.S. road markers and signs. (*1*)[1] This manual, for rural use only, included the octagonal STOP sign with black letters on a yellow background. A red background would have been used but no durable red paint or baked enamel was available. In an

[1]Italic numbers in parentheses identify references on page 83.

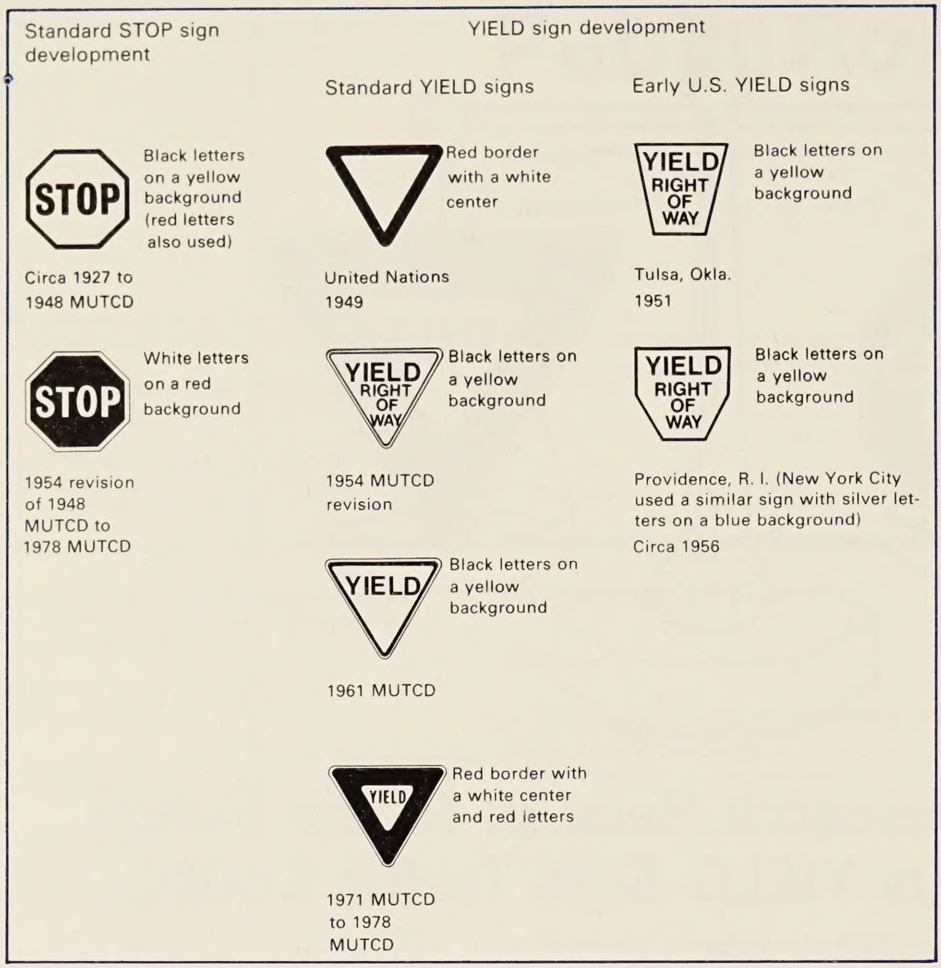

Figure 1.—Historical development of STOP and YIELD signs.

urban manual for street traffic signs, signals, and markings developed in 1927, the octagonal STOP sign had red letters on a yellow background. (*2*) A single manual for both rural and urban use was published in 1935 and included the octagonal STOP sign with black letters on a yellow background. (*3*) Red letters also could be used, and reflecting elements were used in the sign face. In the 1948 MUTCD, the octagonal STOP sign was enlarged from 24 in (610 mm) to 30 in (762 mm). (*4*) The yellow background and black letters continued as standard. The State of California's use of a red porcelain enamel background with white letters was not disapproved in the MUTCD because research was underway to develop dependable red finishes that would be available from competitive sources.

The YIELD sign introduced in 1951 was keystone shaped with black letters on a yellow background and read "YIELD RIGHT OF WAY." Later, an inverted equilateral triangle was used for the YIELD sign in a number of jurisdictions. New York City used a modified six-sided keystone shape with silver letters on a blue background.

By 1951, general use of the red background white lettered STOP sign had begun. Within 4 years, 43 States had adopted this sign, which continues in use today. Florida reported the red STOP signs improved compliance 250 percent.

Both the red STOP sign with white letters and the yellow YIELD sign with black letters were included in the 1954 revisions to the MUTCD. (*5*) Dependable red finishes from competitive sources had become available, making the standardization of the red STOP sign practical. The YIELD sign design was the inverted equilateral triangle and read "YIELD RIGHT OF WAY." The YIELD sign was regarded as experimental, to be used cautiously and only under suitable legislation. In the 1961 MUTCD, the single word "YIELD" became standard. (*6*)

Beginning with the 1971 MUTCD and continuing to the latest edition (1978), the YIELD sign is now an inverted red triangle (adapted from the international symbol for "give way") with "YIELD" in red letters in a white triangular center. (*7, 8*) A few of the yellow triangular and keystone long-message YIELD signs are still in use on entrances and driveways from private property to public streets and highways.

Review of Accident Experience Research

The YIELD sign was introduced because many traffic engineers felt a less restrictive sign replacing the STOP sign would improve driver observance of the remaining necessary STOP signs. However, widespread noncompliance with STOP signs has continued through the years. Many drivers do not stop fully. Others do not slow to any great extent if cross traffic appears light and/or they do not see a police officer.

Table 1.—Historical summary of STOP sign compliance (*9*)

Driver behavior	Compliance (percent)							
	1931	1935	1935	1960	1963	1976	1977	1981
Full stop	47	45	38	20	17	22	12	19
Rolling stop	42	34	42	69	69	48	60	65
No stop	11	21	20	11	14	30	28	16

Table 1 summarizes eight researchers' observations of STOP sign compliance from 1931 through 1981. (*9*) Although different methodologies were used in the individual studies, a significant degree of noncompliance is apparent.

In 1953, the early use of YIELD signs in four cities was reported (*10*):

- Dallas, Texas—With more than 75 installations, many replacing STOP signs, compliance was good.
- Oklahoma City, Oklahoma—One year or more after 28 installations, accidents decreased 9 percent (23 accidents before and 21 accidents after).
- Portland, Oregon—A review of 14 installations indicated accident reduction generally varied inversely with the traffic volume. Accidents decreased at nine intersections, remained the same at three intersections, and increased at two intersections.
- Tulsa, Oklahoma—At 50 locations where YIELD signs were in place over 1 year, accident experience improved. There were no accidents in some locations where two to four accidents had occurred in the previous year. At five typical locations, only 12.6 percent of the vehicles approaching the signs entered the intersection at speeds higher than 10 mph (16 km/h).

At a Wyoming intersection with no control, three accidents occurred during a 9-month period in 1954–1955. (*11*) For the 9-month period following installation of YIELD signs, no accidents occurred.

After YIELD signs were installed in 1957 at two Santa Ana, California, intersections with no control, accidents were reduced from a 2-year-before total of 15 to none during the 6-month-after period. (*12*) The 30 in (762 mm) triangular signs had the message "YIELD RIGHT OF WAY" in black letters on a yellow background. The word "YIELD" was painted on the pavement 75 ft (23 m) before the crosswalk, and a dashed line was painted at the normal stop line. At three additional intersections having less than one accident per month, no accidents occurred during the first 3 months after the YIELD sign was installed.

In the early 1950's, the most frequent use of YIELD signs was at previously uncontrolled intersections in lieu of STOP signs. (*13–15*) In 1951, only one accident was reported during the first 10 months after 20 YIELD signs were installed in Tulsa, Oklahoma. In 1954, after YIELD signs were installed at 17 intersections in Berkeley, California, there were 43 fewer accidents at 12 intersections, 10 more accidents at 4 intersections, and no change in accidents at 1 intersection. Also in Berkeley, accidents were reduced from 15 to 5 (67 percent) at one intersection where the YIELD sign was installed on the low volume legs with no sight restriction. At another intersection, accidents increased from two to nine where the YIELD sign was installed on the high volume legs. After the signs were shifted to the low volume legs, no accidents were reported.

The accident experience where YIELD signs replaced STOP signs in a number of jurisdictions also was reviewed. (*14, 15*) In Napa, California, YIELD signs replaced STOP signs at 17 intersections. A 10-month before-and-after study showed accidents decreased or did not change at 13 intersections and increased by one at 3 intersections. Accidents at the other intersection increased from one to five, but after foliage was trimmed, only one accident occurred at this intersection during the next 10 months.

In 1953, San Francisco, California's, Board of Supervisors contended that drivers were not complying with many STOP signs. Following traffic engineering studies, a proposal recommended replacing 114 STOP signs with YIELD signs, installing 171 YIELD signs and 65 STOP signs at previously uncontrolled intersections, and removing 214 STOP signs—a total of 564 sign changes. Out of the total recommended changes, only 15 STOP signs were replaced with YIELD signs mostly at isolated intersections. At 13 of these intersections accidents increased from 10 during the 1-year-before period to 72 during the 1-year-after period. The increases possibly resulted from inadequate publicity and high minor street volumes that would have been lowered by traffic diversion under the recommended plan.

A 1964 study on the safety of and compliance with STOP and YIELD signs concluded the following (*16*):

- Annual accident rates experience a major temporary decrease after the YIELD sign is installed. For 1 to 2 years after installation, the accident rate rises to some level below that existing for the uncontrolled intersection.

• At uncontrolled and at YIELD-controlled intersections where the lighter volume is controlled, most accidents occurred during daylight hours on wet, snow covered, or icy pavements and where poor sight distance is combined with high approach speeds.

• Under good driving conditions, more accidents occur at intersections where the YIELD sign controls the heavier volume rather than the lighter volume. Installing a YIELD sign on the legs of lighter volume, at previously uncontrolled intersections, tends to reduce accidents.

• Peak-period drivers on the minor street are more aggressive at uncontrolled intersections than at YIELD-controlled intersections.

• At YIELD-controlled intersections, the rate of noncompliance with the maximum legal approach speed to the intersection is low (1 to 2 percent) and relatively constant when the volume of the protected street is greater than or equal to the volume of the controlled street. When the volume on the controlled street is greater than on the protected street, the noncompliance rate rises markedly (13 to 31 percent) as the imbalance in volumes increases.

Table 2 summarizes actual driver behavior during peak and offpeak periods where STOP signs control minor street traffic.

Table 2.—Driver behavior under STOP sign control (*16*)

Behavior of minor street traffic	Period: Peak	Period: Offpeak
	Percent	*Percent*
Vehicle forced to stop because of cross traffic	35 to 40	20 to 30
Voluntary full stop	1 to 9	3 to 12
Proceed under 5 mph	47 to 57	48 to 74
Proceed over 5 mph	5 to 6	2 to 10

1 mph=1.6 km/h

Accident rates for rural Kentucky highways were derived using 1970–1972 statewide accident records. (*17*) Table 3 gives the severity indexes for several kinds of traffic control, followed by the percentage of various kinds of accidents under each control. The severity index was developed using a weighted combination of fatal, injury, and property damage accidents divided by the total number of accidents. All of the kinds of traffic controls included in the study (in addition to STOP and YIELD) are shown to present the relative safety of the several controls and the relationship between kinds of accidents and kinds of control. The table shows there were 29.6 percent rear end or same direction sideswipe accidents under STOP sign control and 56.2 percent of this same kind of accident under YIELD sign control. For angle collisions the reverse was true—51.9 percent under STOP and 22.5 percent under YIELD control. However, the severity index under STOP control (2.70) was much higher than under YIELD control (2.03).

In 1976, traffic controls were evaluated for 53 intersections on low volume roads in Indiana. (*18*) Three-year accident records showed no significant difference in the occurrence of accidents at STOP, YIELD, and uncontrolled intersections. Thirty-one percent of the vehicles failed to fully stop at STOP-controlled intersections. Many of the low volume STOP-controlled intersections caused unnecessary speed changes, stopping of traffic, delays, and increased vehicle operating costs (table 4). Proper management of traffic signs at low volume intersections can improve the productivity of the highway system. (*18*)

A 1981 study determined the operating characteristics and relative hazard associated with two-way stop, yield, and no control at low volume intersections. (*9*) Low volume intersections included minor roadways with less than 500 vehicles per day (vpd) while major roadway volumes ranged up to 10,000 vpd. A total of 140 urban and rural intersections were studied in Florida, New York, and Texas.

Table 3.—Severity indexes and percentages of various kinds of accidents for traffic controls (*17*)

Traffic control	Severity index	Head-on or opposite direction sideswipe	Rear end or same direction sideswipe	Angle collision	Pedestrian	Other collision	Single vehicle	Fixed object	Other
STOP sign	2.70	4.1	29.6	51.9	0.2	1.2	12.0	0.7	0.3
Signal	2.27	6.2	55.9	28.6	0.3	2.2	5.0	2.0	0.2
YIELD sign	2.03	4.0	56.2	22.5	0	3.6	12.0	0	1.6
Flashing beacon	2.45	5.8	51.9	14.9	1.6	7.7	13.3	5.0	0.5
No passing zone	2.72	25.1	28.0	3.9	1.6	8.9	29.7	1.2	1.5
Curve sign	3.13	29.1	9.0	1.9	0.5	4.8	52.5	1.4	0.7
Speed limit zone	2.66	17.3	29.9	5.0	1.7	15.6	27.5	1.1	1.9
Advisory speed sign	2.80	11.6	29.6	3.3	1.3	11.9	38.2	2.8	1.2
Railroad gates or signals	3.81	8.7	18.9	3.1	1.0	46.4	18.9	2.6	0.5
Centerline	2.94	12.8	35.7	2.7	1.4	7.8	35.3	1.4	3.0
Officer or watchperson	2.21	4.4	62.4	1.7	1.7	16.6	9.6	3.1	0.4
Other	2.62	37.4	16.8	2.7	1.4	11.4	27.1	1.3	1.9

Table 4.—Effect of traffic control and major street volume on travel time, stops, and operating costs (*18*)

Traffic control	Major street volume	Mean travel time	Full stop	Rolling stops below 5 mph	Stopping and slowing cost per vehicle
	Vehicles per hour	*Seconds*	*Mean percentage*	*Mean percentage*	*Cents*
No sign:	0–25	7.77	10.83	28.00	0.33
	26–50	—	13.50	28.00	0.36
YIELD sign:	0–25	10.12	14.00	28.00	0.36
	26–50	11.11	16.40	28.00	0.38
	51–100	11.29	20.00	28.00	0.42
STOP sign:	0–25	12.26	59.50	14.25	0.67
	26–50	13.09	67.60	16.80	0.77
	51–100	13.40	71.80	13.03	0.78
	100+	14.65	71.40	13.35	0.78

1 mph=1.6 km/h

Table 5.—Average annual highway agency costs and annual road user savings (*9*)

Major volume	Control change From	To	Average annual highway agency cost Intersection 3-Leg	4-Leg	Expected road user average annual savings per 100 vpd minor roadway volume
			Dollars	*Dollars*	*Dollars*
≤2,000 vpd:	STOP sign	YIELD sign	7	11	240
	STOP sign	No control	5	5	44
	No control	YIELD sign	14	23	196
>2,000 vpd:	STOP sign	YIELD sign	7	11	244
	STOP sign	No control	5	5	155
	No control	YIELD sign	14	23	88

Significant findings include the following:

- Control type has no appreciable effect on accident experience at low volume intersections.
- Travel time is significantly affected by signing, with STOP control producing the longest travel time and YIELD control the shortest.
- Any signing criteria could be standardized throughout the United States.
- Small differences in travel time observed between urban and rural locations were primarily a function of major roadway volume.
- Geometry (three-leg and four-leg) does not play a major role in either the safety or operation of low volume intersections.
- The percentage of intersections experiencing accidents increases significantly at major roadway volumes of 2,000 vpd and again at 4,000 vpd, regardless of control type.
- Travel time increases significantly at major roadways of 2,000 vpd primarily because of increased forced stop rate.
- Sight distance has no discernible effect on either safety or operations at low volume intersections.

In the same study, average annual costs and benefits were computed assuming a 7-year sign service life, a 5 percent discount rate, and a 3 percent annual growth in minor roadway traffic volume (table 5). In no case was conversion to STOP control cost effective; conversion to YIELD control was always cost effective.

In summary, the accident experience research reviewed above reveals a consistent pattern of accident reduction where YIELD signs were installed at previously uncontrolled intersections. There were mixed results, some increase and some decrease in accidents, when STOP signs were replaced by YIELD signs. Some of the increases in accidents were caused by YIELD signs being installed on the legs with the heavier traffic volume or legs with poor visibility.

1983 Handbook on Traffic Control Devices

The 1983 edition of the "Traffic Control Devices Handbook" includes guidelines for selecting STOP or YIELD signs for specific intersections. (*19*) The following should be considered:

- Traffic volume—Usually the heavier volume of traffic should be given the right-of-way.
- Approach speed—Usually the higher speed traffic should be given the right-of-way.
- Highway type—When a minor highway intersects a major highway, usually the minor highway should be controlled.
- Sight distance—Sight distance across the corners of the intersection is the most important factor and is critical in determining safe approach speeds.

The handbook states, "Many of the existing intersections having STOP signs could be converted to the less restrictive YIELD sign without sacrificing safety." The handbook includes a Critical Approach Speed Chart and an example of a typical STOP or YIELD sign selection process.

Comprehension Problems

Some of the problems related to compliance with STOP and YIELD signs may be traced to the other uses of red in the 1978 MUTCD and to the legal requirements for stopping and yielding in many traffic situations to avoid immediate hazards. Originally red was reserved for the STOP sign. Later, red was adapted from international symbols used in the YIELD sign and for a circle with a slash to indicate prohibited movements. Dangerous traffic situations also are indicated by the red WRONG WAY and DO NOT ENTER signs. However, signs using red to signify parking restrictions, prohibited vehicle movements, and towaway zones do not indicate the same degree of danger as the white background, black lettered DO NOT PASS sign, the yellow pennant NO PASSING ZONE sign, and the yellow round railroad crossing advance warning sign. Now, drivers are expected to recognize a wide range of sign shape and color combinations as well as symbols and word messages, take into consideration existing traffic conditions, and act safely and responsibly.

The Federal Highway Administration (FHWA) has initiated a study of driver comprehension of regulatory and warning signs, including the STOP and YIELD signs. The study will identify signs that are difficult to comprehend, develop criteria for determining acceptable comprehension, develop remedial signing, evaluate signing in the laboratory and field, and recommend new and/or modified sign designs.

Current Problems

Although the YIELD sign appears to be an acceptable and desirable alternative to the STOP sign for certain combinations of major and minor street traffic volumes, considerable disagreement exists as to when the YIELD sign should be used in view of safety, cost effectiveness, and liability concerns. The National Committee on Uniform Traffic Control Devices seeks a clear policy and guidelines on when YIELD signs should be used instead of no control or STOP sign control. These guidelines should be based on solid and conclusive accident and operational experience as a function of major and minor roadway volumes, sight distance, vehicle mix, and intersection geometrics. Developing successful guidelines will remain hampered by the lack of such data, although YIELD signs are believed to be more cost effective without sacrificing safety.

As an example of the problems associated with the study of YIELD versus STOP sign use, the Institute of Transportation Engineers (ITE) studied YIELD sign usage and application. (*20*) A wide range of data was requested from States and local jurisdictions, but only limited data actually were received. However, the results reported in 1978 indicate the YIELD sign can be used safely at many intersections. ITE found additional research is needed, particularly in the areas of regulation and enforcement.

Proposal for a Safety and Operational Study of STOP and YIELD Signs

Because of the interest of the National Committee on Uniform Traffic Control Devices in determining the safety of replacing STOP signs with YIELD signs, FHWA would like to determine the scope of the safety and operational problems before a large-scale study is undertaken. As an initial step, FHWA would request from the States a wide cross section of accident data where STOP signs have been replaced in recent years by YIELD signs. Information from the States would include number of accidents by kind and severity, intersection geometry (number of legs), range of approach speeds, existing sight restriction and effect on approach speed, and traffic volumes on major and minor legs.

The data then would be analyzed in-house to determine the scope of the safety problem. Specific questions to be answered would be whether rear end or same direction sideswipe accidents increase and angle collisions decrease where YIELD sign control replaces STOP sign control.

After this initial analysis, FHWA would design an experiment including the specifications for site selection. States would locate control and test sites for replacing STOP signs with YIELD signs based on the site selection criteria. The States would furnish the before data and collect the after data for both the control and test sites. FHWA would consolidate the State data and perform the analysis.

FHWA's Traffic Control and Operations Division would like to receive comments and suggestions on replacing STOP signs with YIELD signs. Correspondence should be addressed to:

Federal Highway Administration, HSR–30
6300 Georgetown Pike
McLean, Virginia 22101

REFERENCES[2]

(*1*) "Manual and Specification for the Manufacture, Display, and Erection of U.S. Standard Road Markers and Signs," *American Association of State Highway Officials,* January 1927.

(*2*) "Manual on Street Signs, Signals, and Markings," *National Conference on Streets and Highway Safety,* 1927.

(*3*) "Manual on Uniform Traffic Control Devices for Streets and Highways," *National Conference on Street and Highway Safety* and *American Association of State Highway Officials,* November 1935.

(*4*) "Manual on Uniform Traffic Control Devices for Streets and Highways," *Public Roads Administration,* Washington, D.C., August 1948.

(*5*) "Revisions to the Manual on Uniform Traffic Control Devices for Streets and Highways," *Bureau of Public Roads,* Washington, D.C., 1954.

(*6*) "Manual on Uniform Traffic Control Devices for Streets and Highways," *Bureau of Public Roads,* Washington, D.C., 1961.

(*7*) "Manual on Uniform Traffic Control Devices for Streets and Highways," *Federal Highway Administration,* Washington, D.C., 1971.

(*8*) "Manual on Uniform Traffic Control Devices for Streets and Highways," *Federal Highway Administration,* Washington, D.C., 1978.

(*9*) W. R. Stockton, R. Q. Brackett, and J. M. Mounce, "Stop, Yield, and No Control at Intersections," Report No. FHWA/RD–81/084, *Federal Highway Administration,* Washington, D.C., June 1981. PB 82 117649.

(*10*) Paul W. Rice, "The Yield Sign," Transactions, *National Safety Congress,* Chicago, Ill., 1953.

(*11*) Robert C. O'Connell, "Experience with Yield Signs," *Traffic Engineering,* October 1956.

(*12*) James C. Ray, "Six Months Use of 'Yield Right-of-Way' Signs," *Traffic Engineering,* October 1957.

(*13*) Donald S. Berry and James H. Kell, "Use of Yield Signs," *Traffic Engineering,* January 1956.

(*14*) James H. Kell, "The Development and Application of Yield Right-of-Way Signs," Research Report No. 27, *Institute of Transportation and Traffic Engineering,* University of California, Berkeley, Calif., January 1958.

(*15*) James H. Kell, "Applications of Yield Right-of-Way Signs," *Traffic Engineering,* July 1958.

(*16*) Jack E. Leisch and Walter A. Barry, Jr., "Effect of Control Devices on Traffic Operations," National Cooperative Highway Research Program Report 11, *Highway Research Board,* Washington, D.C., 1964.

(*17*) Kenneth R. Agent and Robert C. Deen, "Relationship Between Roadway Geometrics and Accidents," Transportation Research Record 541, *Transportation Research Board,* Washington, D.C., 1975.

(*18*) A. K. Bandyopadhyay, "Evaluation of Traffic Control Devices at Intersections of Low Volume Roads and Streets," Report No. CE–TRA–76–2, *Purdue University,* December 1976.

(*19*) "Traffic Control Devices Handbook," *Federal Highway Administration,* Washington, D.C., 1983.

(*20*) "Yield Sign Usage and Application," ITE Technical Council Committee 4A–A, *ITE Journal,* October 1978.

[2]Report with PB number is available from the National Technical Information Service, 5285 Port Royal Rd., Springfield, Va. 22161.

Merton J. Rosenbaum is a highway research engineer in the Traffic Control and Operations Division, Office of Safety and Traffic Operations Research and Development, FHWA. He is involved in research to improve traffic safety and capacity on rural and urban highways. Before joining FHWA in 1961, Mr. Rosenbaum worked for 15 years with the Virginia State Highway Department in highway location and design, traffic and planning, and computer applications.

Making Crossing Structures Accessible for Elderly and Handicapped Pedestrians

by
Richard A. Richter and John C. Fegan

Introduction

Pedestrian overpass and underpass roadway crossing structures installed principally as safety improvements have been ignored by some pedestrians who seem to prefer the shorter, more dangerous, but slightly more convenient at-grade path across a roadway. A small group of the pedestrian population, the elderly and handicapped, however, typically prefer the safer but longer route across a structure. Nevertheless, the crossing structure still may not be a completely satisfactory crossing solution for elderly and handicapped pedestrians if their physical limitations are not compatible with some of the structure's design features. Structure designers have for some time weighed the alternatives for making overpass and underpass crossing structures more serviceable to pedestrians. Of principal interest have been the approaches to the structure. Some handicapped pedestrians, such as those in wheelchairs, need a ramped surface to climb approximately 20 ft (6.1 m) to the walkway of most overpass structures. Other handicapped pedestrians, such as those on crutches, are better able to climb on stairs. Persons with restricted vision can be aided by guidance strips and tactile warning surfaces. Still other handicapped persons avoid relying on such special devices, stating that without uni-

form application, dependence on these devices is dangerous. Highway officials recognize the need to make pedestrian crossings as accessible as possible to all potential users and must deal with the problems of balancing cost with anticipated use, the conflicting demands of different handicapped users, and the trade offs between accessibility and user convenience.

Determining User Needs

A suitable pedestrian crossing structure should be accessible to a degree equal to or greater than the present or proposed accessibility of connecting routes. This can be readily determined if the Priority Accessible Network (*1*)[1] concept has been adopted. The Priority Accessible Network concept involves designating principal access routes for elderly and handicapped pedestrians, prioritizing the upgrading of those routes, and developing full accessibility for all major categories of handicapped pedestrians on each route at one time. As a major component of pedestrian routes, existing crossing structures often would be targeted for conversion to add accessible features or possibly added to the route system as a completely new link to an existing inaccessible network. One approach to determining the degree to which accessibility features should be added is to consider that elderly and handicapped pedestrians exist in a representative percentage within the overall pedestrian population. As the estimated pedestrian volume using a structure increases, so does the usage by the elderly and handicapped pedestrians. Many of the features such as rest areas, benches, lights, and special signs would then take on added importance as the overall pedestrian volume increases.

One of the most difficult aspects of designing a suitable pedestrian crossing structure is determining in advance the volume of use and nature of the users for the proposed crossing. Origin and destination surveys can estimate pedestrian desires to cross a physical barrier, but this potential will not be realized unless a sufficiently easy-to-use and convenient crossing facility capable of generating pedestrian use is provided. In trying to estimate use by the elderly and handicapped, the problem becomes even more difficult. Even if physical barriers are removed at a crossing, specific categories of handicapped persons may not use that particular crossing.

[1] Italic number in parentheses identifies reference on page 88.

Two design philosophies are suggested. One is to survey the area surrounding a proposed pedestrian crossing to estimate the population of elderly and handicapped pedestrians. Then categorize those potential users into specific groups having similar needs for specific design features. The designer then is able to develop the required crossing facility features. Conflicting requirements of some categories of elderly and handicapped can be resolved when the categories are found within the survey area.

The other design philosophy is to assume that the structure will be used by all of the major categories of elderly and handicapped pedestrians and to design the structure, approaches, and end connections with all of the desired features. This approach saves the time and expense of conducting a user survey but may unnecessarily add to the expense of the structure by including features that are not needed and rarely would be used.

A manual has been developed to aid structural designers in choosing what design features to provide and those to avoid, as well as appropriate specifications to insure usable features for the handicapped pedestrian. (*2*)

Two Principal User Categories

Two major groups of elderly and handicapped pedestrians are of principal concern in relation to crossing structures—those in wheelchairs and those who are blind. Wheelchair users need a ramp or mechanical lift to gain the elevation required to cross on a structure. Ramps appear to offer the best solution, but the optimum combination of grades and ramp length is sometimes hard to determine. Users range in their physical capability to travel on steep ramps. As ramp grades are made progressively less steep, they become longer—another undesirable characteristic. The basis for selecting ramp grades and the tolerance of users to long ramps have been investigated and are described later in this article.

The other user category, the blind, are not a homogeneous group when needs are considered. In addition to ranging from the completely blind to the "legally blind" with limited sight, there are varying degrees of philosophies and techniques used by the blind for pedestrian movement. Some blind pedestrians prefer to perfect movement techniques allowing them to move without auxiliary aids. Others can facilitate travel by using supplemental aids for guidance, even though these aids are not provided everywhere. Typically, handrails are provided and serve to direct blind pedestrians across structures. A more recent development being considered for the blind pedestrian is the tactile strip or textured surface located for guidance along travel paths and for warning across paths. Blind pedestrians identify these strips with a long cane.

Until recently, not much was known about the kinds of surfaces that can be detected and identified using a cane or the criteria for determining a slipproof surface on ramps and stairs. A method for specifying such surfaces when designing pedestrian overpass and underpass crossing structures was needed as well as a better understanding of the abilities of elderly and handicapped pedestrians to travel on sloping ramped walkways.

Research on Accessibility Features

Ramp grades

Research was conducted to determine the length, gradient, and rest area configurations for long ramps. (*3*) Previous research had investigated gradients of ramps up to 40 ft (12.2 m) long. (*4*) Pedestrian overpasses could, however, require ramps of up to 240 ft (73 m) long. Six ramp gradients from 1:10 to 1:16 were tested using 102 disabled subjects. On long ramps, the most important predictors of an individual's performance were his or her physical capabilities, age, sex, and other factors such as motivation, physical strength, and stamina. Physical characteristics of the ramp are much less important, but among these characteristics, gradient is the best predictor of performance.

Analysis of the performance of manual wheelchair users indicates a relationship between users' abilities to climb ramps to a certain vertical height and the ramp gradient. The recommended gradients in table 1 accommodate 80 percent of manual wheelchair users.

Table 1.—Ramp gradients for various climbing heights

Ramp gradient	Maximum vertical height	Maximum linear distance exclusive of rest area
	Feet	*Feet*
1:10.1 to 1:11.0	9	91.3/99.4
1:11.1 to 1:13.0	14	156.0/182.5
1:13.1 to 1:15.0	16	210.2/240.5
1:15.1 to 1:16.0	20	302.7/320.5

1 ft=0.305 m

Landing locations

For long ramps, 85 to 95 percent of test subjects were able to travel a considerable distance to their first rest stop. Subsequent rest stops need to be closer together. The location of the first rest stop is between 4.5 and 6.0 vertical ft (1.4 and 1.8 vertical m) depending on ramp gradient. Thus, the first rest stop should be located at 45 ft (13.7 m) for a 1:10.0 ramp and at 95 ft (29 m) for a 1:15.9 ramp. Results of field tests indicate that ramp configuration (straight, dogleg) does not affect performance. (*3*) However, helical ramps are more difficult to negotiate and require a more gradual gradient for the user to perform as well as on a straight ramp.

Slip resistance of walkway surface materials

Twelve level walkway surfaces were tested for slip resistance (table 2). Coefficients of friction greater than 0.3 are adequate for level pathways, but 0.4 or 0.5 is preferred. Thus, all of the tested materials meet this criterion. To convert these coefficients of friction to those for sloped surfaces, the following equation is used:

$$y = \frac{x}{\cos a} + \tan a$$

Where,
y=Static coefficient of friction on an inclined surface.
x=Static coefficient of friction on a horizontal (level) surface.
a=Angle on incline.

Table 2.—Static coefficients of friction for various surface materials (level surfaces)

Surface material	Shoe material	
	Leather (dry)	Neolite (dry)[1]
Brushed concrete New, against the brush	0.75	0.90
Asphalt tile Waxed, heavy use area	0.56	0.47
Smooth metal Rusted slightly	0.54	0.49
Asphalt Old parking lot	0.53	0.64
Checker plate Rusted moderately	0.50	0.64
Quarry tile Unglazed 6 in × 6 in tile	0.49	0.60
Thermoplastic Used on crosswalk	0.45	0.86
Brick pavers On stair, new no finish	0.43	0.73
Exposed aggregate Pea gravel, heavy traffic	0.41	0.57
Granite Stairs, old, exterior	0.40	0.66
Plywood "A" side With grain, no finish	0.39	0.75
Plywood "A" side Against grain, no finish	0.38	0.51

[1] Neolite was sanded smooth and flat.
1 in=25.4 mm

Table 3.—Static coefficients of friction for level and inclined surfaces

Level surface	Gradient[1]					
	1:20 (5%)	1:18 (5.55%)	1:16 (6.25%)	1:14 (7.14%)	1:12 (8.33%)	1:10 (10%)
Minimum preferred for external surfaces:						
0.80	0.851	0.856	0.861	0.874	0.882	0.904
0.75	0.801	0.806	0.812	0.824	0.832	0.854
0.70	0.751	0.756	0.761	0.774	0.782	0.804
0.65	0.701	0.706	0.711	0.723	0.732	0.753
0.60	0.651	0.656	0.661	0.673	0.682	0.703
0.55	0.601	0.606	0.611	0.623	0.632	0.651
0.50	0.551	0.556	0.561	0.573	0.582	0.603
Minimum acceptable for external surfaces:						
0.45	0.500	0.505	0.511	0.521	0.531	0.552
0.40	0.450	0.455	0.461	0.472	0.481	0.502
Minimum acceptable for roofed areas:						
0.35	0.400	0.405	0.411	0.422	0.431	0.452
0.30	0.350	0.355	0.361	0.372	0.381	0.402

[1] The figure for the inclined surfaces is a calculated value. This value indicates that as the gradient of the walkway increased, a material with a higher coefficient of friction becomes necessary.

The minimum coefficients of friction need to be greater for sloping ramps than for level surfaces. For a 1:10 ramp, for example, the minimum coefficient of friction required is 0.502 and the preferred value is 0.603. This corresponds to 0.40 and 0.50 for level walkways. Table 3 illustrates the minimum coefficients of friction acceptable for roofed areas and external surfaces. Fewer than one-half of the surfaces when tested with leather soles meet the acceptable minimum, and only brushed concrete reaches the preferred level.

Surface Detectability

Twenty-two visually impaired people with little or no functional vision traversed orientation and warning test panels, and their abilities to detect each panel using a cane were recorded. Three qualities of surface materials were considered—surface texture, rebound, and impact sound. The tests indicated that the sound made as the cane traveled the walkway surface was the major factor in detectability. Texture of the panel also was useful.

Orientation cues

Five tasks are particularly troublesome for visually impaired persons attempting to cross roadways: Crossing open space, traversing nonperpendicular path intersections, finding the appropriate place to cross a street, finding an end connection from a broken or uneven path, and finding a dirt or gravel path end connection from a paved path.

Six countermeasures improved performance of the test subjects. These include the following in descending order of performance:

- A wooden shoreline—a 1 in × 6 in × 8 in (25 mm × 152 mm × 203 mm) board staked to the ground paralleling the route.
- A sound-emitting device that produces a loud "chirp-chirp" noise to indicate an appropriate crossing location and time.
- A metal plate.
- A wooden plate—a 4 ft × 8 ft × 0.5 in (1.2 m × 2.4 m × 12 mm) sheet of plywood.
- A rubber mat.
- A carpet mat.

As with testing on surface detectability, landmarks that produce loud noise when struck with a cane are helpful as orientation cues; distinctive rebound, as in the case of the rubber mats, is less helpful.

Needed Research

Relationships need to be developed between the volume of anticipated usage by representative categories of elderly and handicapped pedestrians and the design features intended to insure accessibility for the users within each category. Design features need to be identified as to their importance for accessibility, that is, whether they are absolutely essential for accessibility or are optional features that merely would facilitate movement of the elderly and handicapped pedestrians.

REFERENCES[2]

(*1*) J. A. Templer et al., "Development of Priority Accessible Networks," Report No. FHWA–IP–80–8, *Federal Highway Administration,* Washington, D.C., January 1980.

(*2*) R. A. Richter and C. L. King, "Guidelines for Making Crossing Structures Accessible to Elderly and Handicapped Pedestrians," Report No. FHWA–IP–83–5, *Federal Highway Administration,* Washington, D.C., December 1983.

(*3*) J. A. Templer, J. D. Wineman, and C. M. Zimring, "Guidelines for Accommodating the Handicapped on Crossings," Report No. FHWA/RD–82/124, *Federal Highway Administration,* Washington, D.C., December 1983.

(*4*) J. A. Templer and J. D. Wineman, "The Feasibility of Accommodating Physically Handicapped Individuals on Pedestrian Over and Undercrossing Structures," Report No. FHWA/RD–79/146, *Federal Highway Administration,* Washington, D.C., September 1980. PB No. 81 155004.

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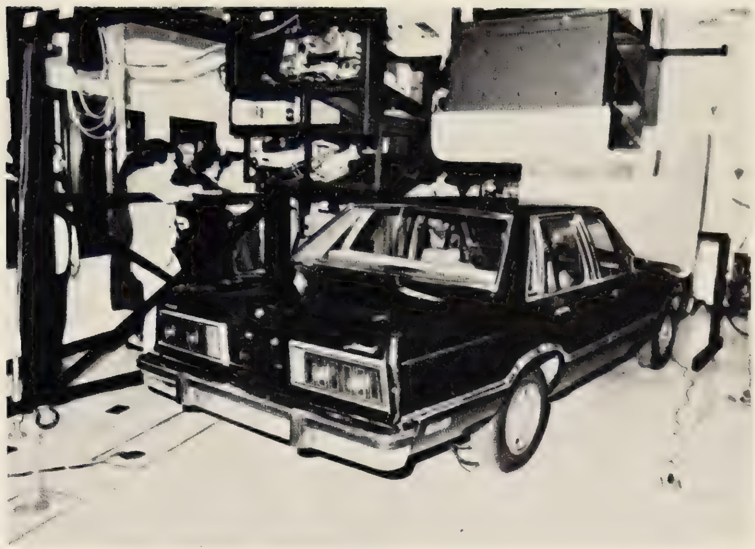
[2]Report with PB number is available from the National Technical Information Service, 5285 Port Royal Rd., Springfield, Va. 22161.



A Highway Simulator Analysis of Background Colors for Advance Warning Signs

by
Harry S. Lum, King M. Roberts, Richard J. DiMarco, and R. Wade Allen

Background

The Manual on Uniform Traffic Control Devices (MUTCD) mandates orange as the background color for most construction and maintenance warning signs and yellow as the background color for all other warning signs (except when orange is specified). (*1*)[1] However, because the symbols on the STOP AHEAD and YIELD AHEAD signs (fig. 1) are predominantly red, questions have been raised as to whether these advance warning signs installed in construction and maintenance zones should have a yellow background which may provide greater contrast than an orange background.

[1] Italic numbers in parentheses identify references on page 96.

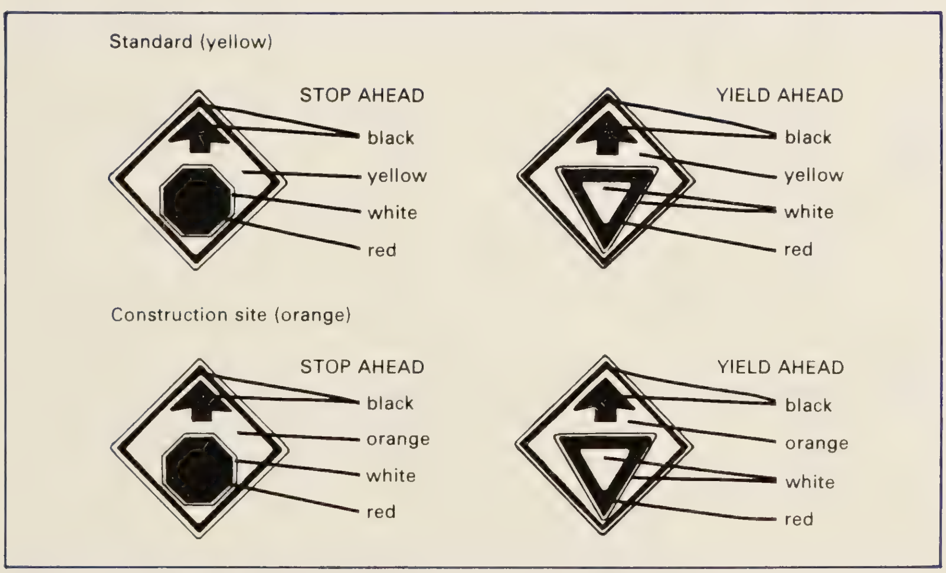


Figure 1.—Advance warning symbol signs tested.

This article discusses an experiment that used the Federal Highway Administration (FHWA) Highway Driving Simulator (HYSIM) to compare the effectiveness of an orange background versus a yellow background on the symbol STOP AHEAD and YIELD AHEAD signs. The measure of sign effectiveness was drivers' recognition distance of the signs posted on the simulated roadway. Early recognition is desirable because drivers have more time to adjust speed or maneuver their vehicle to meet the requirements of a specific road situation.

The experiment also provided the first application of the HYSIM and demonstrated its capability.

Apparatus

HYSIM is a real-time, fixed-base, interactive system (*2*); its major functional capabilities are summarized in figure 2. The primary features of the system include the following:

- A realistic car cab environment that includes all the basic controls and displays found in a 1980 Ford Fairmont sedan.
- A full-sized forward field-of-view (50° lateral × 40° vertical) visual display that provides a representation of key roadway alinement elements that change in synchronous response to driver inputs.
- Full speed-range vehicle dynamics including a representation of engine speed and brake responses and two degree-of-freedom (sideslip and yaw rate) lateral/directional equations of motion.
- Projection of prephotographed, color, high-resolution slide images of signs that move in registry with the oncoming roadway.
- Provision for auditory cues common to the car/highway environment (engine whine, road noise, siren, crash, and tire thump).
- Measurement and collection of driver performance data (such as lane deviation, control applications, and speed).
- Centralized simulator control including initiation and termination of experimental runs, closed-circuit television monitoring of simulator status and driver performance, and two-way voice communication with the driver.

Roadway Features and Test Signs

A driveable roadway with two 12 ft (3.7 m) wide traffic lanes and a white 10/30 ft (3/9 m) (line/gap) centerline and continuous solid white edgelines was depicted. Roads intersecting the main road at various angles provided an appropriate context for some signs, such as "merging traffic." Curvature near some intersections provided realism and diversity.

Foggy weather was simulated on the screen by superimposing a veiling luminance on each sign presentation. Accident boundaries, invisible to subjects, were arbitrarily set at 5 ft (1.5 m) left of the centerline and 3 ft (0.9 m) to the right of the right edgeline. A crashing sound and a temporary freezing of vehicle movement signified encroachment of the accident boundaries.

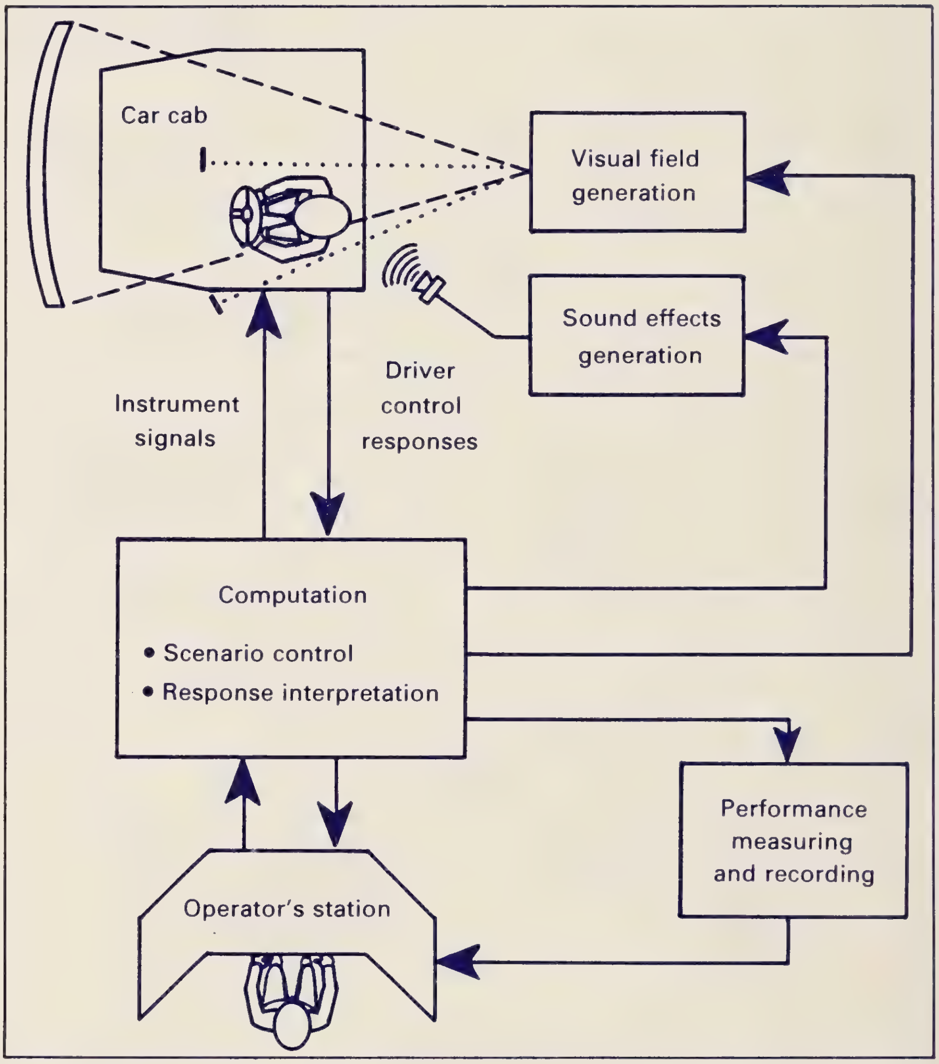


Figure 2.—Simplified simulator functional diagram.

The four signs of interest, STOP AHEAD and YIELD AHEAD each with a yellow and an orange background, were presented as a subset of regulatory, warning, and guide signs. A total of 21 signs were presented randomly in three speed zones—35, 45, and 55 mph (56, 72, and 89 km/h). Signs were varied as much as possible in form, color, and message content. Signs generally seen on roadways were used because sign perception and not memory recall was of primary interest.

The simulation study was as realistic and diverse as possible to imitate real-world driving habits. When an advance warning symbol STOP AHEAD or the YIELD AHEAD sign was presented, the appropriate regulatory STOP or YIELD sign was shown next without intervention of other signs. Speed limit signs indicated speed zones, and route and guide signs were added primarily to maintain subjects' interest and attention.

Subjects and Procedure

Subjects were solicited through an advertisement in a local newspaper. Respondents to the advertisement were screened for a valid driver's license and absence of serious visual or physical handicaps. Sixteen males and 16 females were selected to participate in the experiment. Subjects were divided equally by sex and by four age groups—16 to 29 years, 30 to 44 years, 45 to 59 years, and 60 years and older.

First, subjects examined the artwork used to make the sign slides used in the experiment. The meaning of each sign was described. For training on the HYSIM, subjects were scheduled in pairs and trained together, taking turns "driving" the simulator. When a subject was not driving the simulator, he or she observed from the passenger seat.

Training was conducted in several steps. The subject was told to get a "feel" for driving the simulator. Then he or she was asked to respond to each sign by operating the dimmer foot switch as soon as he or she recognized the sign projected on the screen. Also, the subject was told to identify each sign orally using the intercom system. The separation between the response and identification function was to minimize the delay between recognition and response time. Training continued until the subjects appeared comfortable driving the simulator and could identify all signs.

Actual data collection sessions lasted about 20 minutes and consisted of two runs—one run for clear visibility conditions and one for simulated fog. For each visibility condition, subjects drove one of two scenario patterns using 35, 45, and 55 mph (56, 72, and 89 km/h) speed zones. One pattern consisted of the following sequence of the three speed zones: 45, 35, 55, 45, 55, and 35 mph (72, 56, 89, 72, 89, and 56 km/h). The other scenario was 45, 55, 35, 45, 35, and 55 mph (72, 89, 56, 72, 56, and 89 km/h). In each speed zone of the sequence, the subjects saw two of the four test signs together with the appropriate regulatory signs in a rural scenery. When signs with an orange background were presented, there was nothing in the background to suggest construction activity. Other roadway signs were presented randomly. This method of presenting the test signs minimized the possibility of a subject learning effect from earlier training sessions.

Reward/Penalty Schedule

A reward/penalty schedule was used to motivate subjects to encounter signs at or near the design speed of the roadway, respond as soon as they recognized a sign, and correctly identify the sign. (*3*) After a run, the subjects were apprised of their performance and resulting monetary payoff. The reward/penalty schedule allowed $5 for completing a run and from $0.01 to $0.10 for each sign correctly identified. The subject lost $0.50 for violating the speed limit and for each sign incorrectly identified and $1 for each accident incurred. Total payoff was rounded to the nearest dime.

Analysis Plan

Six independent variables used in the experiment were divided into between- and within-group designs. Variables in the between-group were a subject's age and sex, visibility condition, and the speed scenario pattern. To eliminate a possible subject learning effect resulting from earlier training, the variable scenario pattern and the variable visibility were balanced out over age and sex. Each of the speed scenario pair was presented to one subject of each age group, sex, and visibility condition.

The within-group variables consisted of the variable speed zone at three levels—35, 45, and 55 mph (56, 72, and 89 km/h)—and the variable sign class—two advance warning signs with the yellow and orange backgrounds.

The resulting between-group and within-group designs are presented in tables 1 and 2, respectively. Each cell in table 2 represents a particular subject's responses (recognition distances), and the complete entries of the 24 cells represent a subject's record of each experiment. There were 768 (32 subjects × 24 responses) data points for analysis.

The dependent variable and data inputs for the analysis consisted of computer-recorded sign recognition response distances indicated by the subjects when they activated the car's dimmer foot switch. Also, a "response code" was recorded and later characterized the subjects' intercom oral sign identification as correct, incorrect, forgot to respond, or distracted. Thus, it was possible to identify from the experimenter's log entries data points to be aborted.

Subjects correctly identified 3,979 signs of the 4,032 sign presentations (32 subjects × 2 scenarios × 21 signs × 3 speeds). The remaining 53 sign presentations were identified as "aborts" by the response code data and were excluded from the data set and subsequent analysis. Only 6 of the 19 different signs used in the experiment were misidentified. (The STOP AHEAD and YIELD AHEAD signs presented to the subjects with different background colors were considered as two signs for the purpose of correct or incorrect identification.) The STOP AHEAD sign with a yellow background was misidentified once and the 35 mph (56 km/h) speed limit sign was misidentified as 55 mph (89 km/h) six times. Other multiple misidentifications were the route marker sign ("Route 22" with an arrow indicating straight ahead) and three guide signs. No clear pattern of misidentification was found among the age groups.

Table 1.—Experimental design for between-group independent variables

Sex:	16 Males				16 Females			
Visibility condition:	Clear	Fog	Fog	Clear	Clear	Fog	Fog	Clear
Scenario pattern:	A	B	A	B	A	B	A	B
Age[1]: 16–29	1	1	1	1	1	1	1	1
30–44	1	1	1	1	1	1	1	1
45–59	1	1	1	1	1	1	1	1
60 and older	1	1	1	1	1	1	1	1

[1] The "1" in each cell represents one subject randomly assigned to a cell who meets the age and sex criteria.

Table 2.—Experimental design for within-group independent variables

Sign type and background color	Visibility condition	Speed zone 35 mph	45 mph	55 mph
Orange YIELD AHEAD	Clear			
	Foggy			
Yellow YIELD AHEAD	Clear			
	Foggy			
Orange STOP AHEAD	Clear			
	Foggy			
Yellow STOP AHEAD	Clear			
	Foggy			

1 mph = 1.6 km/h

Data Analysis

The data were analyzed by the analysis of variance technique. As shown in table 3, subjects' recognition distances were not dependent on sex, order of presentation of visibility condition, and speed scenario pattern. However, age, speed zone, and sign color have a significant effect on subjects' recognition distances. Significant interactive effects were noted between sign color and age, sign color and speed zone, and sign color, age, and speed zone. On the other hand, speed and age did not significantly interact. In other words, recognition distance across sign color was not altered significantly because of speed and age. The significance of each effect is discussed below.

Effect and interaction of age on recognition distance

A driver's age is the single most significant factor in determining recognition distance. Table 4 presents the mean recognition distances for the YIELD AHEAD and STOP AHEAD advance warning signs by background colors, visibility conditions, and age groups. For the 16–29 age group, the recognition distance was 298 ft (90.8 m) averaged over visibility conditions, background colors, and test signs; for the 30–44 age group, the average recognition distance was 250 ft (76.2 m); for the 45–59 age group, it was 150 ft (45.7 m); and for the 60 and older age group, it was 90 ft (27.4 m). Recognition distance decreases with age—the youngest age group has the longest or best recognition distances. The age effect is consistent with both background colors and visibility conditions.

Table 4 also demonstrates the interaction between sign background color and age. For the YIELD AHEAD sign under both visibility conditions, age interacts with background colors. For example, for the YIELD AHEAD sign under the clear visibility condition, the differences in recognition distance between the two background colors for the four age groups are 36, 57, 29, and 9 ft (11.0, 17.4, 8.8, and 2.7 m), respectively. The differences in recognition distances are not constant within the limits of sampling fluctuations, and thus it is apparent that age and sign color interact. When the response pattern of the four age groups, the three speeds, and a background color is compared with the response pattern of the age and speed groups and the other background color, the pattern again is dissimilar, indicating a three-factor interaction between sign color, speed, and age (fig. 3). This significant interaction is not clearly understood but may be attributed to sampling fluctuation.

Moreover, the different recognition distances between the two background colors under the clear visibility condition for both the STOP AHEAD and YIELD AHEAD signs show that the 30–44 age group benefits more from the yellow background than the youngest age group (57 ft [17.4 m] versus 36 ft [11.0 m] for YIELD AHEAD and 111 ft [33.8 m] versus 56 ft [17.1 m] for STOP AHEAD). On the other hand, under foggy conditions, the youngest age group benefits more from the yellow background than all the other age groups. The reason for this inconsistency between the two younger age groups under the two visibility conditions is not clear.

Table 3.—Analysis of variance summary for STOP AHEAD and YIELD AHEAD signs. Type 1 error (alpha=.10)

Independent variables:	Clear		Foggy	
	STOP AHEAD	YIELD AHEAD	STOP AHEAD	YIELD AHEAD
Main effects:				
Between group				
Age	0.055	0.055	0.035	0.027
Visibility condition	NS[1]	NS	NS	NS
Scenario pattern	NS	NS	NS	NS
Sex	NS	NS	NS	NS
Within group				
Sign color	0.011	0.0006	0.006	0.0000
Speed zone	0.030	0.0006	0.001	0.049
Interactions:				
Color and age	NS	0.014	NS	0.007
Color and speed	0.094	0.001	NS	0.0359
Speed and age	NS	NS	NS	NS
Color, speed, and age	NS	0.035	NS	NS

[1] NS=Not significant.

Table 4.—Mean recognition distance of STOP AHEAD and YIELD AHEAD signs by background colors, visibility conditions, and age groups

YIELD AHEAD

Visibility conditions	Background color	Age group 16–29	30–44	45–59	60 and older
		Feet	*Feet*	*Feet*	*Feet*
Foggy	Yellow	270	216	139	97
	Orange	212	166	94	62
		58	50	45	35
Clear	Yellow	395	345	209	118
	Orange	359	288	180	109
		36	57	29	9
Averaged over background color		309	254	156	97

STOP AHEAD

Visibility conditions	Background color	Age group 16–29	30–44	45–59	60 and older
		Feet	*Feet*	*Feet*	*Feet*
Foggy	Yellow	240	172	97	72
	Orange	195	146	89	54
		45	26	8	18
Clear	Yellow	384	386	225	130
	Orange	328	275	167	81
		56	111	58	49
Averaged over background color		288	245	145	85
Overall average		298	250	150	90

1 ft=0.305 m

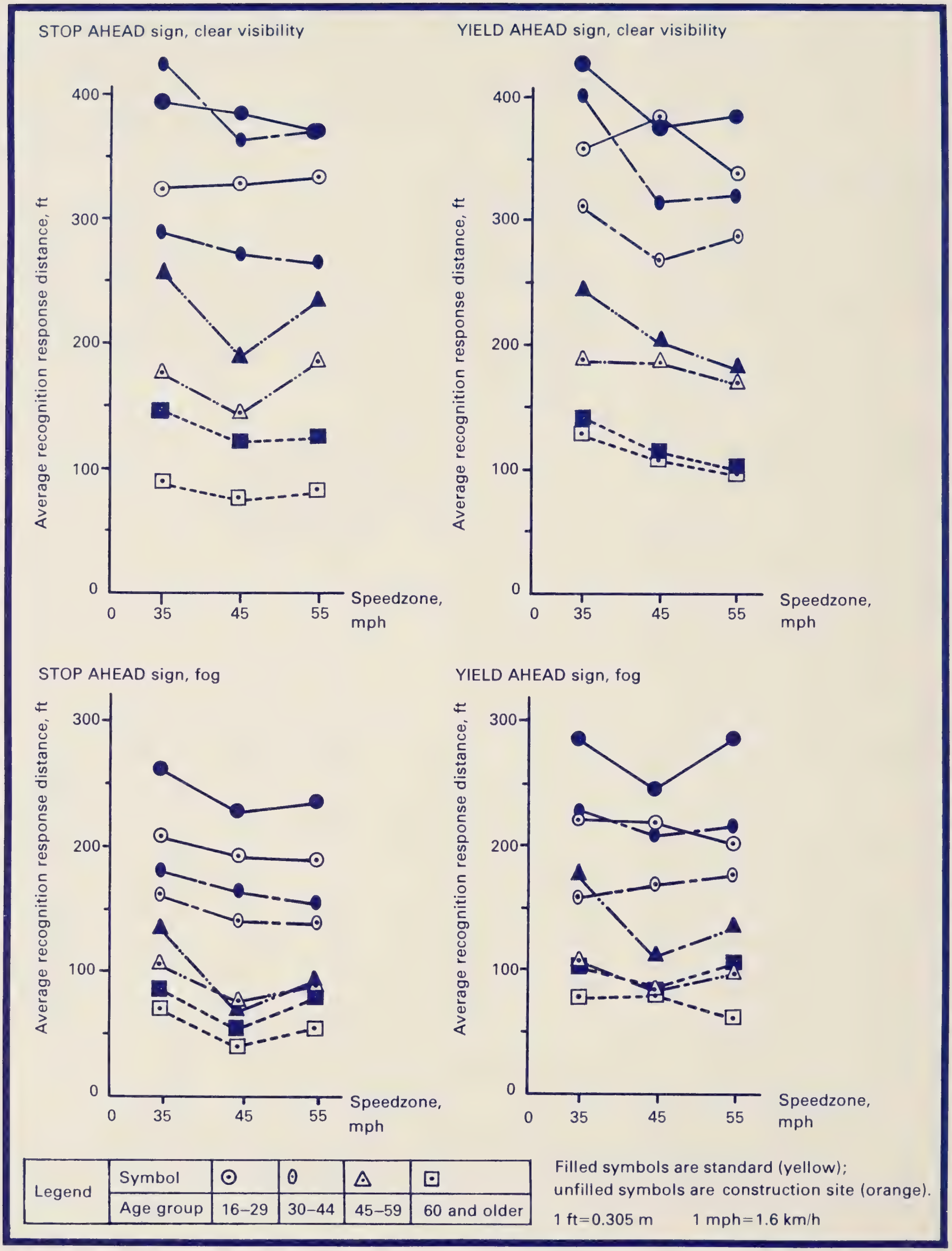


Figure 3.—Effects of age and speed on recognition response distance.

Table 5.—Mean recognition distance of STOP AHEAD and YIELD AHEAD signs by background colors and visibility conditions

Background color	STOP AHEAD Clear	STOP AHEAD Foggy	YIELD AHEAD Clear	YIELD AHEAD Foggy
	Feet	*Feet*	*Feet*	*Feet*
Yellow	281	145	267	180
Orange	213	121	234	133
Difference between colors[1]	68	24	33	47

[1]All differences between the two colors statistically significant (t–test) at the 5 percent level.
1 ft=0.305 m

Effects and interaction of background colors on recognition distance

Table 3 shows that both speed and age interact with background color, possibly because the white insert in the YIELD AHEAD symbol made the sign more recognizable than the solid red insert in the STOP AHEAD sign with orange background (fig. 1). Table 5, which presents the mean recognition distance averaged over age groups, sex, and speed zones, helps to interpret these interactions. For both symbol signs and visibility conditions, signs with a yellow background are recognized earlier (at a greater distance) than signs with an orange background. Also, under the clear visibility condition, the recognition distance is markedly shorter for the YIELD AHEAD sign (33 ft [10.1 m]) than for the STOP AHEAD sign (68 ft [20.7m]). However, under the foggy condition, the YIELD AHEAD sign was more visible than the STOP AHEAD sign (47 ft [14.3 m] versus 24 ft [7.3 m], respectively). These conflicting results indicate a significant interaction between background color and both age and speed.

Effect of speed on recognition distance

The analysis of variance results show that the three speed zones of 35, 45, and 55 mph (56, 72, and 89 km/h) have a significant effect on recognition distance. This effect is not unexpected because an increased travel speed decreases the time between when the driver recognizes the sign message and subsequently passes the sign. Speed was included in the experimental design to detect any interaction between speed and subjects' age on recognition distance. The analysis shows no interaction; the subject's response time (stimulus and reaction) is constant over the three speed zones indicating that recognition distance is a function of vehicle speed.

Comparison With Results From Other Studies

Recognition distances also were obtained for signs other than the STOP AHEAD and YIELD AHEAD signs in the driving scenario. For the YIELD sign, the recognition distance was 524 ft (157 m) averaged over all subjects under the clear visibility condition. Although the results of this experiment cannot be compared directly with past research, a field study on the perceptibility of traffic control signs at night does provide some insight as to the validity of the results. (*4*) In the field study, recognition distance was measured for an inverted triangle sign with a red border fabricated with an "engineer grade" and also with "high intensity grade" reflective material. The sign was identical in format to the YIELD sign used in this experiment except that the white insert did not have the word YIELD. The recognition distance for both reflective materials was approximately 650 ft (198 m). The distance was averaged over the 12 subjects participating in the study, and scaling the distance by the ratio of the sign sizes (HYSIM/Gothelp = 0.88) gives an effective recognition distance of 570 ft (174 m) as compared with 524 ft (157 m) measured in this experiment. It should be noted, however, that the 12 subjects in the field study (11 males and 1 female) ranged from 19 to 43 years in age, yielding an average of 28.7 years. This is considerably lower than the 44.3 average age for the 32 subjects of this experiment, half of whom were over 45 years old. Allowing for the difference in the age range should bring the average recognition distance in the field study closer to that of this experiment.

Summary and Discussion

Judging from the results of the experiment described in this article, HYSIM successfully demonstrated its capability to simulate roadway conditions. No major operational problems were found, and none of the subjects experienced ill effect from being "cooped up" in the simulator.

The results of the simulation experiment clearly show that the STOP AHEAD and YIELD AHEAD symbol signs are recognized more quickly with a yellow background than with an orange background. In general, younger drivers exhibit earlier (longer) recognition distances than older drivers for these advance warning signs under both clear and foggy visibility conditions.

The shortest recognition distance recorded was 54 ft (16.5 m) by the 60 and older age group for the STOP AHEAD sign with an orange background and under the foggy condition. An appropriate advance warning sign generally is placed 250 ft (76 m) or more in advance of a STOP or YIELD sign. Even with short recognition distances, drivers would have adequate time (distance) to respond to the STOP or YIELD sign if the drivers detected the advance warning sign. It is conjectured that recognition distance could be increased by increasing color contrast with a wider white border on the STOP AHEAD and YIELD AHEAD symbols.

REFERENCES

(*1*) "Manual on Uniform Traffic Control Devices," *U.S. Department of Transportation, Federal Highway Administration,* Washington, D.C., 1978.

(*2*) K. M. Roberts, "The FHWA Highway Driving Simulator," *Public Roads,* vol. 44, No. 3, December 1980, pp. 97–102.

(*3*) A. C. Stein, S. H. Schwartz, R. W. Allen, "Use of Reward/Penalty Structures in Car-Driving Research," NASA Report No. CT–2060, *Proceeding of the 14th Annual NASA/University Conference on Manual Control,* Los Angeles, Calif., 1978.

(*4*) J. Gothelp, "The Perceptibility of Traffic Control Signs at Night: A Field Study on the Effect of a New Type of Retroreflective Material," Report No. IZF 1979–C1, *Institute for Perception TNO,* The Netherlands, 1979.

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Richard J. DiMarco has been involved in analysis and simulation of dynamic systems since 1968. As assistant project engineer, he participated in all phases of HYSIM's development, including system development and software design; systems integration and checkout; and delivery, installation, and operator training. He has conducted experiments and performed analyses of man/machine performance, involving simulation of a wide range of vehicles (automobiles, trucks, aircraft, and ships) and encompassing a variety of factors such as manual control, motion effects, psychophysiological impairment caused by alcohol, and external information presentation.

R. Wade Allen has been involved extensively in man/machine systems research since 1960. He was the project engineer during the later stages of HYSIM's development, including system documentation, delivery, installation, and operator training. He has been responsible for a major portion of the automobile driving simulator development and an ongoing series of experimental studies of physiological impairment of driving performance. Mr. Allen also has been a principal investigator on various signing and delineation research programs.

Stopped Vehicles on Freeway Shoulders

by
Brenda C. Kragh

Introduction

From 1977 to 1979, the California Department of Transportation investigated the safety problem of vehicles stopped on freeway shoulders and found that, on the average, fatal accidents involving at least one vehicle stopped on the shoulder accounted for almost 5 percent of all freeway fatal accidents for the State. (*1*)[1] More than one-half of these accidents occur at night or under limited lighting conditions, when traffic volumes are low and vehicle headlights are on. California Department of Transportation specifically cited sleepiness and intoxication as major causes of these accidents and suggested that drivers fail to realize that the cars they are approaching (and believe they are following) actually are not moving.

The Texas State Department of Highways and Public Transportation made similar observations in reviewing State accident records and hypothesized that fatigued drivers, especially drivers of long-haul trucks, pull their vehicle onto the shoulder to rest. These vehicles then become targets for other vehicles, with the striking vehicle showing no sign of evasive action.

Because of the concerns expressed by California and Texas regarding the safety problem of vehicles stopped on roadway shoulders, the Federal Highway Administration (FHWA) budgeted research to determine the magnitude of the problem, assess the exposure (opportunity for an accident) of stopped vehicles, identify causal factors, and consider possible countermeasures to decrease the incidence and/or severity of shoulder accidents.

Before initiating a full-scale study, preliminary inhouse activities were conducted to determine if it was feasible to collect exposure data of vehicles stopped along freeways. This exposure, of course, depends on the number and the length of stay of the parked/stopped vehicles and the traffic volume on the adjacent roadway. This article describes the inhouse activities that were conducted, which included a literature review, developing a study plan, and limited data collection and analysis.

Literature Review

The literature review revealed that few studies deal specifically with accidents involving vehicles stopped on freeway shoulders. However, related studies address broad topics such as rear end accidents (both on and off the roadway) (*2, 3*), run-off-the-road accidents (including rollovers and striking fixed objects), and accidents involving stopped or slow moving vehicles. (*4*) Several studies deal with driver reaction to stopped or slow moving vehicles on or along the highway. (*5, 6*) Other studies focus on countermeasures intrinsic to run-off-the-road accidents, including shoulder width, type, and design

[1] Italic numbers in parentheses identify references on page 101.

and roadside delineation and signing. Vehicle countermeasures include emergency flashers, color-coded vehicle lights (*7*), light placement (*8*), automatic braking based on vehicle closing rates (*9, 10*), and use of the triangular symbol sign at a parked vehicle.

Two Bureau of Motor Carrier Safety (BMCS) studies look specifically at the problem of commercial vehicles in collisions involving vehicles parked or stopped on highway shoulders. (*11, 12*) The original study analyzes selected accidents from BMCS files from 1967 to 1975; the followup study extends the data through 1978. Of the 2,345 accidents investigated during the 12-year span, 75 involved vehicles parked or stopped on the shoulder. It must be remembered that BMCS files include only reported accidents of regulated Interstate carriers, and to be reported, the accident must involve a minimum of $2,000 in property damage or a personal injury that requires treatment away from the accident scene. This limited study population does not allow generalization to the overall vehicle population. It is interesting to note, however, that in the original study, drowsiness is suggested as a major cause of highway shoulder accidents ("rumble" shoulders and frequent rest areas are named as possible countermeasures), and in the followup study, inadequate rest by commercial drivers is determined as the initial cause. Other noteworthy observations from the followup study include the following:

- Fifty-six percent of the accidents involved drivers who dozed or fell asleep at the wheel when the striking vehicle left the roadway.
- Ninety-two percent of the accidents were rear end collisions.
- Fifty-five percent of the accidents occurred between 11:30 p.m. and 5:30 a.m.
- Fifty-three percent of parked vehicles were parked for reasons other than mechanical problems.

Although data were not available on the extent of nonfatal accidents of this kind, the total population of national fatal accidents, as provided by the Fatal Accident Reporting System (FARS), was accessed for 1975–1979 for those fatal accidents involving a collision with a parked vehicle on the shoulder to obtain information on the magnitude of the problem.[2] These data reveal the following:

- An average of 4.4 percent (from 3.8 percent in 1975 to 5.5 percent in 1979) of all fatal accidents that occur on Interstate and other limited-access roads involve a collision with a parked vehicle on the shoulder.
- An average of 32 percent of all fatal accidents involving vehicles parked on the shoulder occur on Interstate and other limited-access roads. By comparison, these highways carry approximately 25 percent of the total vehicle-miles (vehicle-kilometres) traveled.
- An average of 67 percent of all fatal accidents involving vehicles parked on the shoulder occur when it is dark or dark but lighted.
- An average of 535 fatal accidents involving vehicles parked on the shoulder occur each year out of an average of 42,153 fatal accident types on all type roadways.
- An average of 597 fatalities (1.12 fatalities per fatal accident) occur as a result of vehicles parked on shoulders on all type roadways.

It was apparent from the FARS data and observations by the California and Texas transportation departments that the number of accidents involving vehicles parked on roadway shoulders was identifiable and significant. However, it was important to assess the relative significance of the number of accidents and to determine the feasibility of identifying an appropriate exposure measure and collecting relevant exposure data. The following study plan describes the in-house feasibility effort.

Study Plan

Segments approximately 22 miles (35 km) long were selected along five limited-access roads in the Washington, D.C., metropolitan area for the feasibility study. Each segment was to be traveled in both directions (constituting a "run") by a two-person data collection team—a driver/observer and an observer/recorder. Data would be collected only on Tuesdays, Wednesdays, and Thursdays between 2–4 a.m., 6–9 a.m., 11–1 p.m., and 3:30–6:30 p.m. The data collection team usually completed two runs during each of the four time periods on each of the five segments. It was believed that the traveling conditions on the days chosen would fluctuate less than on Monday, Friday, and weekend travel periods and, thus, would be more comparable. A comprehensive study, if undertaken, would involve data collection on all days of the week to represent the influence of alcohol and traffic variations. The time periods were chosen to represent day/night and rush hour and non-rush hour traffic volumes. The length of the time periods was considered adequate to complete at least one run per segment under usual traffic volumes at peak congestion. Because it was believed that the length of stay of a vehicle stopped on the shoulder was relatively short, a second run would be performed, if time permitted, to see if vehicles documented in the first run still were parked on the shoulder.

[2] Fatal Accident Reporting System (FARS) computer search, September 1980, U.S. Department of Transportation, National Highway Traffic Safety Administration, National Center for Statistics and Analysis, Washington, D.C.

A response sheet (fig. 1) was devised to document the length of stay of a stopped vehicle, kind of vehicle, and reason for stopping along the roadway. The sheet briefly described the study and gave instructions for returning the sheet. The data collection team documented times, roadway and vehicle characteristics, and other miscellaneous information and noted whether a response sheet had been left. A total of 100 response sheets were distributed at the team's discretion.

Before actual data collection, appropriate FHWA field offices and law enforcement officials were informed of the general background and study plan as well as the area within their jurisdiction that would be covered.

Data Collection

During late August and early September 1980 the two-person team traveled each roadway segment by car on the scheduled day and time. Upon arriving at the starting point of the run, the time, shoulder type, and odometer reading were recorded. During these runs, the 100 response sheets were distributed at the team's discretion to vehicles stopped on the shoulder. As a general rule, vehicles that were parked on or near an exit or entrance ramp or near

This is NOT a Ticket !!

It's a Study

The Federal Highway Administration is conducting a study concerning stopped vehicles on shoulders. As part of this study, we are asking you to complete the questions below and return the form in the self-addressed stamped envelope within 5 days. Upon receiving your accurately completed form, we will send you $10 for your trouble. No names will be used in the report and no further contact with you will be made.

Time you pulled onto the shoulder: ________________

Time you continued your journey: ________________

Road Name: ________________

Licensed Plate Information: State: ____________ No: ________

Vehicle Type ☐ Car ☐ Pick-up/Van ☐ Motorcycle
☐ Truck (# axles?___) ☐ Other (Explain)

Reason for Stopping ☐ Mechanical ☐ Flat Tire ☐ No Gas
☐ Change Driver ☐ Read Map ☐ Rest/Sleep
☐ Bad Weather ☐ Accident ☐ Assist Other Motorist
☐ Stopped for Violation ☐ Other (Explain)

Reason You Left Vehicle ☐ Did Not Leave Vehicle
☐ Get Help
☐ Picked Up By Other Motorist/Police/Friend
☐ Other (Explain)

Amount of Time Car Remained on Shoulder:

Minutes: 0 1 5 10 15 30 45 60

Hours: 1 2 3 6 12 18 24

Days: 1 2 3

Your Name and Address (for us to send you $10) ________________

____

____

____

Figure 1.—Data response sheet.

bridge abutments were not given response sheets because the team felt it was unsafe to pull onto the shoulder. However, these vehicles do constitute a hazard and ignoring them makes the sample population unrepresentative and would not be acceptable in a comprehensive study because it would bias the results.

Identifying data were logged for most observed parked vehicles. When motorists were in their parked car, the team explained the study and offered to telephone for help. No attempt was made to awaken sleeping motorists, often observed during the 2–4 a.m. and 6–9 a.m. runs.

Data Analysis

Traffic volumes and accident data for the study segments were received from the Maryland and Virginia highway departments for the period covered by the study. However, because so few accidents occurred during this period, these data were not analyzed.

A breakdown of the 62 response sheets that were returned reveals that 53 percent of the vehicles stopped were cars, 28 percent were trucks, and 19 percent were pickups or vans. Of the 100 forms distributed, 57 were placed on cars, 31 on trucks, and 12 on pickups or vans. Table 1 shows that 47 percent of the respondents reported remaining on the shoulder for 1 hour or less; 60 percent for 2 hours or less; 71 percent for 3 hours or less; and 89 percent for 9 hours or less. It should be noted that a timeline was available on the response sheet to depict the length of stay, and a separate place was provided for the actual time of arrival and departure (fig. 1). Because of inconsistencies between the two time measures on several response sheets (probably because of misinterpretation of the timeline) the timeline data were disregarded.

The results shown in table 2 imply that the major reason for involuntarily stopping on a roadway shoulder is because of mechanical problems (37 percent), and the major reason for voluntarily stopping is to rest or sleep (18 percent).

Although 60 percent of the respondents reported that they remained with their vehicle, the representativeness of this figure is questionable. In addition to the written explanation of the study, those awake drivers remaining with their vehicle received a verbal explanation by the data collection team and personally were encouraged to return the response sheet. This personal contact may explain why drivers who remained with their vehicle were more likely to return the response sheet than those who received only the brief written explanation.

Because most stopped-vehicle accidents occur at night when the ratio of trucks to cars is generally higher, the 17 truck responses were analyzed. Although this is a very small sample, 41 percent of the truck drivers indicated that they stopped on the shoulder to rest or sleep. However, this sample constitutes 64 percent of all respondents who stopped to rest or sleep. On the other hand, the 35 percent of the truck drivers who stopped for mechanical problems accounted for only 26 percent of all respondents who stopped for mechanical problems. Similar to the BMCS findings, these results imply that drivers of trucks, more often than drivers of cars, stop voluntarily (to rest or sleep) rather than involuntarily (because of mechanical problems).

It rained only once while exposure data were being collected. This sudden downpour, which occurred during the 3:30–6:30 p.m. run and lasted about 9 minutes, greatly decreased visibility. On that run, the team observed a dramatic increase in the number of vehicles pulling onto the shoulder—10 vehicles that were documented and more that were not during that 9 minutes compared with a total of 19

Table 1.—Reported length of stay on limited-access roadway shoulder

Length of stay	Frequency	Percent	Cumulative Frequency	Cumulative Percent
Minutes				
5–15	14	23.0	14	23.0
16–30	5	8.0	19	31.0
31–60	10	16.0	29	47.0
61–120 (1–2 hours)	8	13.0	37	60.0
121–180 (2–3 hours)	7	11.0	44	71.0
181–240 (3–4 hours)	3	5.0	47	76.0
241–300 (4–5 hours)	2	3.0	49	79.0
301–360 (5–6 hours)	3	5.0	52	84.0
361–540 (6–9 hours)	3	5.0	55	89.0
541–720 (9–12 hours)	1	1.5	56	90.5
721–1,440 (12–24 hours)	2	3.0	58	93.5
1,441–2,880 (24–48 hours)	3	5.0	61	98.5
2 days	1	1.5	62	100.0
Total	62	100.0		

Table 2.—Reported reason for stopping on limited-access roadway shoulder

Reason for stopping	Frequency	Percent	Cumulative Frequency	Cumulative Percent
Mechanical	23	37	23	37
Rest or sleep	11	18	34	55
Flat tire	6	10	40	65
Assist other motorist	5	8	45	73
Out of gas	4	6	49	79
Read map	3	5	52	84
Change driver	2	3	54	87
Other (explain)	8	13	62	100

vehicles for the entire 30-minute run. Because of the storm's short duration, many of these drivers probably proceeded on their way after only a brief stop. The exposure, or accident potential, during that storm undoubtedly changed several times. Not only did the volume of traffic change abruptly, but the average speed of traffic also changed abruptly with the decreased visibility. In future studies on exposure of vehicles stopped on shoulders, data should be collected during varying degrees of visibility and adverse weather conditions.

Conclusions

Several changes could be made to make data analysis more accurate if this kind of study were to be repeated. These would include format changes on the response and data collection sheets to clarify data received, especially for kind of vehicle and length of stay. Identification coding of distributed response sheets to reflect roadway, time, and approximate location also would facilitate matching of respondent with collection team data. The use of several three-person teams (driver, observer, and data recorder), instead of a single two-person team, would improve data recording accuracy and completeness. Also, two or more teams closely following one another could better record the frequency of vehicles stopped for short durations. Shortening the time between runs and comparing data gathered by each team would better estimate length of stay. Using a tape recorder so that data could be documented at a later time would free the observer(s) to collect more accurate and complete data. Lighted digital clocks would increase the accuracy of time data and facilitate time data collection. Also, longer time intervals throughout the day would allow repeated runs within that interval to increase observations of vehicles stopped for short durations.

Although there were deficiencies, this study showed that collecting exposure data for vehicles stopped on roadway shoulders is feasible. Budget constraints prevented more extensive research on this topic, but similar research should be pursued in the future. When the extent of the problem has been determined and appropriate countermeasures evaluated, recommendations can be made to mitigate this problem.

REFERENCES[3]

(*1*) "Freeway Fatal Accidents," Annual Reports of the Divisions of Operations and Traffic Engineering, *California Department of Transportation,* Sacramento, Calif., 1977–1979.

(*2*) R. G. Mortimer and D. V. Post, "Evaluation of Rear-End Collision Data for Determining Vehicle Rear-Lighting and Signaling Priorities," Hit Lab Reports, vol. 3, No. 4, *Highway Safety Research Institute,* December 1972.

(*3*) D. C. Andreassend, "Vehicle Conspicuity at Night," Australian Road Research Board Proceedings, Vol. 8, Road Safety and Traffic Authority, *University of Western Australia,* August 1976.

(*4*) B. Farachi et al., "Safety on Motorways, Rear-End Collisions: Diagnosis of an Accident," *Autostrade,* vol. 13, No. 8, Societa Autostrade, Italy, August 1971.

(*5*) R. W. Lyles, "Effective Warning Devices for Parked/Disabled Vehicles, Executive Summary and Final Report," Report Nos. FHWA/RD–80/064 and –80/065, *Federal Highway Administration,* Washington, D.C., October 1980. PB Nos. 81 156929 and 81 158396.

(*6*) R. L. Knoblauch and H. N. Tobey, "Safety Aspects of Using Vehicle Hazard Warning Lights, Executive Summary and Final Report," Report Nos. FHWA/RD–80/101 and –80/102, *Federal Highway Administration,* Washington, D.C., September 1980. PB Nos. 81 217739 and 81 217747.

(*7*) T. H. Rockwell and R. R. Safford, "An Evaluation of Automotive Rear Signal System Characteristics in Night Driving," *Ohio State University, Engineering Experiment Station,* June 1968.

(*8*) L. C. Owen, "The Controversy Over Rear Lighting and Signaling on Motor Vehicles," International Auto Safety Conference Compendium, 1970.

(*9*) J. Shefer and R. J. Klensch, "Harmonic Radar Helps Autos Avoid Collisions," Radio Corporation of America, IEEE Spectrum, *Institute of Electrical and Electronics Engineers,* New York, May 1973.

(*10*) "Coming Closer: Radar Braking for Automobiles," Automotive Engineering, vol. 82, No. 2, *Society of Automotive Engineers,* New York, February 1974.

(*11*) "Special Study: Commercial Vehicles in Collisions Involving Vehicles Parked or Stopped on Highway Shoulders," *Federal Highway Administration, Bureau of Motor Carrier Safety,* Washington, D.C., June 1977.

(*12*) "Up-Date on Special Study: Commercial Vehicles in Collisions Involving Vehicles Parked or Stopped on Highway Shoulders," *Federal Highway Administration, Bureau of Motor Carrier Safety,* Washington, D.C., November 1979.

[3]Reports with PB numbers are available from the National Technical Information Service, 5285 Port Royal Rd., Springfield, Va. 22161.

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Recent Research Reports You Should Know About

The following are brief descriptions of selected reports recently published by the Federal Highway Administration, Offices of Research, Development, and Technology. The Office of Engineering and Highway Operations Research and Development (R&D) includes the Structures Division; Pavement Division; Construction, Maintenance, and Environmental Design Division; and the Materials Technology and Chemistry Division. The Office of Safety and Traffic Operations R&D includes the Systems Technology Division, Safety and Design Division, Traffic Control and Operations Division, and Urban Traffic Management Division. The reports are available from the source noted at the end of each description.

When ordering from the National Technical Information Service (NTIS), use PB number and/or the report number with the report title.

Design of Work Zone Flagger's Vest, Report No. FHWA/RD–83/008

by Systems Technology Division

This report discusses a study to develop a design for the flagger's vest that would provide adequate visibility both during the day and at night. Photographs of flaggers in a typical work environment were analyzed to determine how the vest is seen by motorists. Several vest designs also were examined under day, dusk, and night viewing conditions.

For use during the day, the vest should be made of a fluorescent orange material. For night use, white or silver retroreflective tape trimming is required. The tape pattern should be recognizable from the front, side, and back and should outline the figure of a flagger to distinguish the individual as a flagger. An acceptable vest is illustrated in the report.

The results of the study will be used to propose a change to the Manual on Uniform Traffic Control Devices. The report should be of interest to those involved in the development and use of safety devices for highway workers.

The report may be purchased from NTIS.

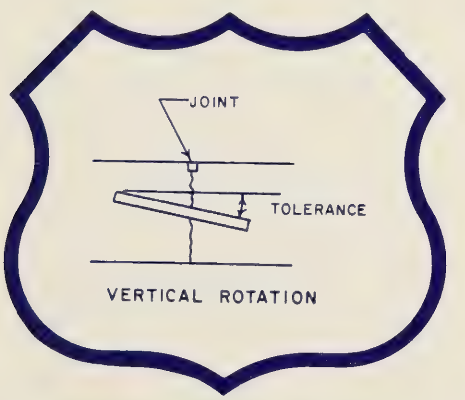
Estimates of Air Pollution Near Signalized Intersections, Report No. FHWA/RD–83/009

by Construction, Maintenance, and Environmental Design Division

Air pollution levels in the vicinity of simple signalized intersections were investigated. A thorough review of the literature was performed and a new, simplified predictive model was developed. The

new model, known as the Texas Intersection Model (TEXIN), incorporates the MOBILE–2 and CALINE–3 computer programs with a set of established shortcut traffic and excess emissions techniques. The result is an efficient computer program that can estimate carbon monoxide levels near simple, signalized intersections given minimal geometrical, meteorological, and traffic parameters. The TEXIN Model was compared with experimental data near intersections and with corresponding simulations by the Intersection Midblock Model (IMM) and other intersection models. The TEXIN Model only requires approximately 10 percent of the inputs and the computer time required by the IMM and also predicts more accurate pollution levels.

The report and the TEXIN computer program may be purchased from NTIS.



Investigation of Location of Dowel Bars Placed by Mechanical Implantation, Report No. FHWA/RD–82/153

by Pavement Division

This report describes the results of an interim phase of a study concerned with the restoration of load transfer to existing jointed concrete pavements. Overall performance of a pavement joint was evaluated in relation to the physical placement of the dowel bar.

Five pavement sections were selected to determine the compliance to specifications of dowel bars placed by mechanical implantation and in basket assemblies. A 1 percent stratified random sample of bars was selected for coring to determine depth, horizontal and vertical rotation, and vertical alinement. Measurements also were made with a metal detector on additional bars.

Alinement and rotation problems were found with the mechanically placed dowels; much better results were obtained with the basket assemblies. Saw-cut location affected longitudinal alinement on both basket and implanted dowels. After 3 years of traffic, no pavement distress related to dowel bar misplacement had occurred, even for locations with dowel bars with extremely large horizontal and vertical rotation.

The report may be purchased from NTIS.

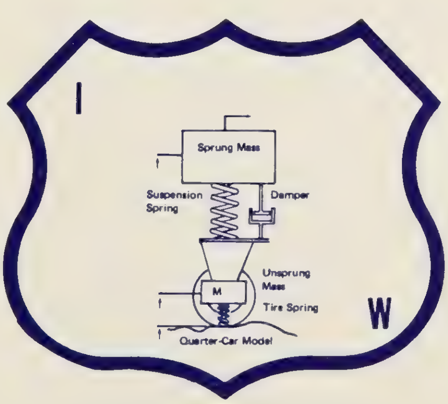
Calibration Services for Pavement Survey Equipment, Executive Summary, Report No. FHWA/RD–82/134, and Final Report, Report No. FHWA/RD–82/135

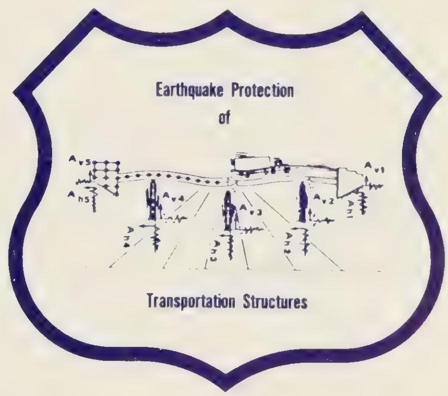
by Pavement Division

These reports discuss the investigation of pavement survey equipment to determine what equipment is in use, what calibration services are required, and how these services can be provided. The major pavement survey equipment in use are the locked-wheel skid tester, response-type road meters, and dynamic-structural-capacity equipment. Other equipment in use or under development are profilometers, British Pendulum Testers, sand-patch gear, outflow meters, Mu Meters, falling-weight deflectometers, and keyboard-pavement-distress survey equipment.

Calibration needs of the equipment are identified in the reports as are candidate calibration services, which are evaluated by a rating scheme. A mobile calibration scheme was selected to provide services to skid testers, roughness meters, structural-capacity devices, and microtexture and macrotexture equipment. A pilot plan and a full program plan were developed for the national implementation of these services. Analysis and recommendation of a funding scheme also are included in the reports.

The reports may be purchased from NTIS.





Earthquake Resistant Bridge Bearings, Vols. I and II, Report Nos. FHWA/RD–82/165 and FHWA/RD–82/166

by Structures Division

These reports describe a study to identify and evaluate the state-of-the-art of using bearings to increase the earthquake resistance of bridges. Volume I, **Concepts,** discusses classical uses of bearings and current trends in applying bearings to earthquake resistance. Among the concepts considered for increased earthquake resistance are isolation, energy dissipation, and displacement restraint.

The bearing force and displacement levels were analyzed in three bridges that experienced bearing failure during earthquakes. Also, criteria were developed for evaluating the performance of earthquake-resistant bridge bearings. Several bearing design concepts that satisfy the performance characteristics to varying degrees are presented and discussed in the report. The most promising concepts were tested and the results presented. Finally, design guidelines for seismic-resistant bridge bearings are presented.

Volume II, **NEABS Computer Program**, contains the user instructions, source documentation, and program listing of the NEABS (Nonlinear Earthquake Analysis of Bridge Systems) computer program used in the study. NEABS is a FORTRAN IV program developed for nonlinear dynamic analysis of long, multiple-span bridge systems.

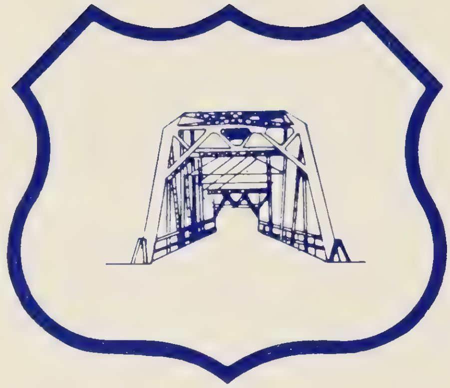
The program can evaluate dynamic time history response to applied dynamic loadings and/or support excitations (rigid or multiple) prescribed at the base of the bridge columns and abutments. To efficiently analyze a bridge structure modeled with both linear and nonlinear elements, a linear/nonlinear element indication array is defined for monitoring the behavior of these elements throughout the analysis process. The program uses a step-by-step direct integration procedure. Either the constant acceleration or the linear acceleration method can be chosen for integration.

The reports may be purchased from NTIS.

Innovative Methods of Upgrading Structurally and Geometrically Deficient Through Truss Bridges, Report No. FHWA/RD–82/041

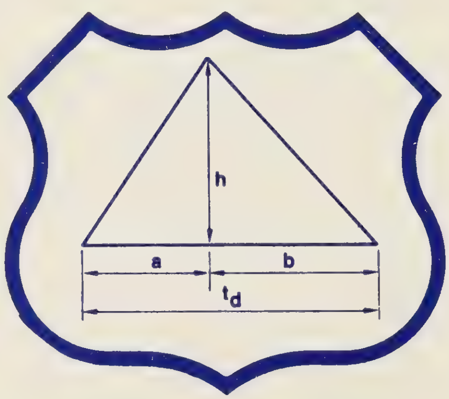
by Structures Division

This report investigates current practices in several States to upgrade truss bridges, reviews



state-of-the-art literature, evaluates information from the Federal Highway Administration bridge inventory, and provides examples of truss bridge rehabilitation. Rehabilitation methods are analyzed to identify problems, limitations, and construction procedure. Specifications and drawings are included in the report and cost comparisons between rehabilitation and replacement are made. Recommendations for future research are given.

The report may be purchased from NTIS.



Local Design Storm, Vols. I–IV, Report Nos. FHWA/RD–82/063–066

by Structures Division

Improved methods for highway storm water drainage require information on the temporal distribution of rainfall (hyetograph) and the average rain intensity. The triangular design hyetograph method, a practical method to provide the local storm hyetograph for design of highway storm drainage facilities, is based on the methods of moments, using and preserving the statistical mean of the first time moment of rainstorms. The method is proposed as a trade off between theoretical sophistication and practical simplicity. A total of 293,946 rainstorms from hourly and 5 to 60 minute precipitation data were analyzed to provide the statistical values of the hyetograph parameters for the United States.

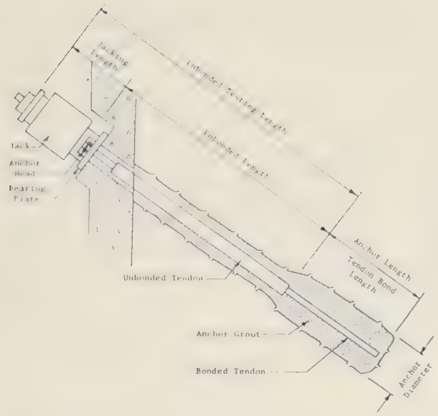
Volume I, **Executive Summary,** briefly describes the background and objectives of the research project, the methodology and procedure of the first-moment triangular design hyetograph method, and results of statistical analyses of the rainfall data.

Volume II, **Methodology and Analysis,** discusses existing methods to describe the temporal distribution of the rainfall of a design storm and discusses different definitions of rainstorms. The theory of the first-moment triangular design hyetograph method is presented. Details of the rainstorm data used are described. Also discussed are the results of the statistical analysis of the data from which a national map of the value of the nondimensional peak rain time of the triangular hyetograph is developed for use in highway storm drainage designs.

Volume III, **Users Manual,** presents a users guide of the procedure to establish the local design hyetograph. Also presented are users guides and listings of two computer programs to perform statistical analyses of rainfall moments for triangular hyetographs and for frequency analyses of rainfall depth-duration-return period relation.

Volume IV, **Tabulation of Sample Detail Results of Statistical Analysis,** summarizes in 84 tables the results of statistical analysis of the mean, standard deviation, and range of rainstorm parameters for two sample stations.

The reports may be purchased from NTIS.



Tiebacks, Executive Summary and Final Report, Report Nos. FHWA/RD–82/046 and FHWA/RD–82/047

by Structures Division

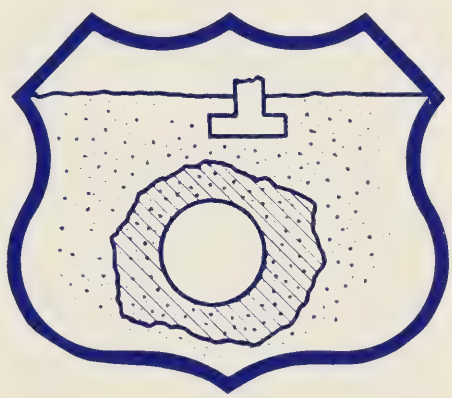
A tieback, a structural device that increases foundation stability, consists of a steel tendon posttensioned between a substructure and an anchorage in undisturbed ground at the end of a predrilled borehole. Injected material bonds the steel tendon to the ground surrounding the borehole. The tendon midlength is left unbonded and elongates elastically when posttensioned.

Tiebacks are a relatively new concept developed primarily by construction contractors specializing in foundation excavation support systems. In the United States, tiebacks began to be used as part of the permanent support of a structure in the early 1970's following earlier trials in other parts of the world. However, the reports indicate some reluctance in the United States to specify tiebacks as permanent support elements for highway structures until more data are available on the life expectancy of tiebacks and on the ability of some foundation soils to sustain long term tieback anchoring loads without excessive movement. Tiebacks are being incorporated successfully in such highway applications as retaining walls, tunnel portals, and bridge abutments. They also may be used for resisting hydrostatic uplift of structures and for stabilizing cut slopes.

These reports summarize the state-of-the-art for tiebacks, describe construction techniques for highway applications, discuss the causes of the few reported failures, assess the problems of corrosion protection and creep behavior, and develop recommended design specifications and testing procedures to insure long life to permanent tiebacks.

The reports encourage greater confidence in the use of tiebacks by concluding that permanent tiebacks installed in rock or in sandy soils can support a variety of structures with insured long term performance and that tiebacks can be used successfully in cohesive soils if the steel tieback tendons are protected adequately against corrosion and if tieback load tests are made to verify that the design load can be carried.

The reports may be purchased from NTIS (Stock Nos. PB 83 178350 and PB 83 178368).



Design and Control of Chemical Grouting, Vols. 1–4, Report Nos. FHWA/RD–82/036–039

by Structures Division

Chemical soil grouting is an accepted construction practice but one that is difficult to evaluate because it does not visibly change the ground surface. Problems associated with the use of chemical grout injection to strengthen or render impermeable in situ soil masses that are to be excavated for transportation structures were addressed by the researchers to improve concepts, controls, and the resulting effectiveness of subsurface chemical grouting.

Volume 1, **Construction Control,** reviews chemical grouting practice and techniques to measure grouting quality and performance. Results of laboratory and field efforts to improve the evaluation of grout distribution are presented. These include the use of geophysical remote sensing techniques such as electrical resistivity, acoustic velocity, borehole radar, geotomography, and acoustic emission.

Volume 2, **Materials Description Concepts,** discusses unconfined compression tests and creep tests conducted on laboratory specimens to investigate the influence of preparation and testing procedures for grouted soils, field sampling effects, and how to determine whether a soil is groutable.

Volume 3, **Engineering Practices,** briefly introduces chemical grouting design philosophy and discusses important geotechnical considerations, chemical grout properties, performance prediction methods, and planning steps for the injection process. Quality control methods are outlined, with emphasis on the need for accurate (preferably automatic) measurements of grout flow rates, pressures, and volumes, and real time evaluation of these data. Guide specifications are presented.

Volume 4, **Executive Summary,** summarizes the findings of the study to improve design and control techniques for chemical grouting in soils.

The reports may be purchased from NTIS.

Implementation/User Items "how-to-do-it"

The following are brief descriptions of selected items that have been completed recently by State and Federal highway units in cooperation with the Office of Implementation, Offices of Research, Development, and Technology, Federal Highway Administration. Some items by others are included when they have a special interest to highway agencies. Requests for items available from the Office of Implementation should be addressed to:

Federal Highway Administration
Office of Implementation, HRT-1
6300 Georgetown Pike
McLean, Virginia 22101

Development of a High Pressure Water Jet for the Rapid Removal of Concrete, Report No. FHWA–TS–83–206

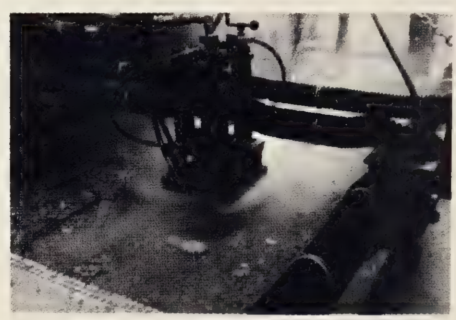
by Office of Implementation

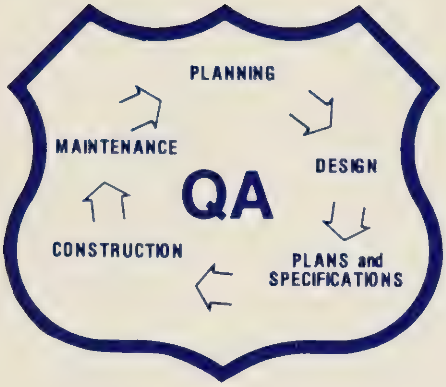
The repair of portland cement concrete pavements and bridge decks is a labor-intensive effort. Because of this, the feasibility and cost-effectiveness of using high pressure water jets for rapid removal of concrete have been under investigation for several years. This report discusses the design, fabrication, and field evaluation of a prototype concrete removal system that uses water cavitation erosion technology.

In October 1982 the system was field tested on a bridge deck in Virginia and demonstrated concrete removal rates as high as 16.5 ft^3 (0.46 m^3) per hour. The one major problem was the limited mobility of the equipment. Work is underway to redesign the equipment for improved mobility.

The report also includes a cost analysis and system comparison as well as conclusions and recommendations from the study. The report should be of interest to maintenance and bridge engineers concerned with bridge deck repair.

The report may be purchased from NTIS.





Quality Assurance for Local Governments, Report No. FHWA–IP–83–1

by Office of Implementation

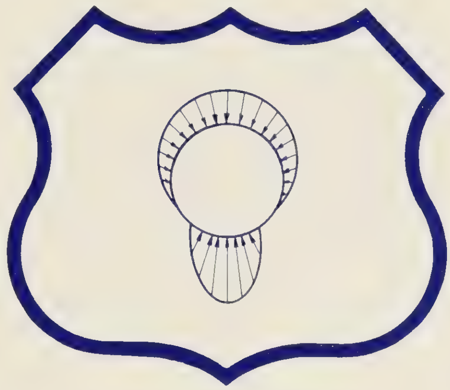
The quality of work performed on roads directly influences the useful life of the facility, maintenance costs, levels of service, and user costs. This report was designed to assist local government units in developing a management system and quality control and testing program to insure a particular level of quality in road and highway construction. The manual was developed with the assistance of a panel of local government engineers. It does not establish what level of quality is required or what must be done to insure the desired level of quality. Rather, it assists local governments in determining the level of quality desired, methods of insuring that level, and available alternatives if specifications are not met.

The report may be purchased from NTIS.

Structural Design Manual for Improved Inlets and Culverts, Report No. FHWA–IP–83–6

by Office of Implementation

In addition to conveying drainage across or from the highway right-of-way, culverts also must carry construction and highway traffic and earth loads. Designing culverts and culvert inlet structures for these loads is the focus of this manual, which provides structural design methods for culverts and improved inlets. Manual methods



for structural analysis are included with a complete design procedure and example problems for both circular and box culverts. These manual methods are supplemented by computer programs contained in the appendixes. Example standard plans have been prepared for headwalls, wingwalls, and side-tapered and slope-tapered culverts for both single- and two-cell inlets. Tables of example designs are provided for each standard plan to illustrate a range of design parameters.

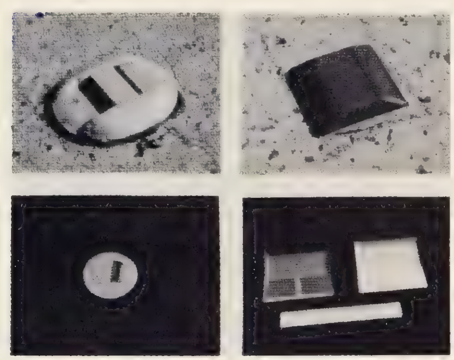
The report may be purchased from NTIS.

Rapid Set Epoxy Adhesive for Pavement Markers, Report No. FHWA–TS–83–209

by Office of Implementation

Because of the increasing use of raised pavement markers for roadway delineation, a more rapid-setting epoxy adhesive was needed to reduce the disruption to traffic during marker placement and increase tolerance of the climatic conditions under which markers are placed. The rapid-set epoxy adhesive 118–AF was evaluated in Mississippi and Oklahoma in a large-scale field application. These field tests indicated that the adhesive performed well. At 77° F (25° C) there is sufficient cure within 15 minutes to open the installation area to traffic. Because of low viscosity of the hardener, however, the adhesive is not compatible with some epoxy machines currently in use.

The report may be purchased from NTIS.



Post-Mounted Delineators, Report No. FHWA–TS–83–208

by Office of Implementation

Throughout the United States, various reflectorized post-mounted delineators are used to aid motorists, especially at night and during adverse weather. This report summarizes the results of a study to evaluate various kinds of post-mounted delineators in eight States.

The report describes the post delineators that were evaluated and includes a discussion on installation, maintenance, and reflectivity. Accident and cost data also are included. Generally, the flexible posts were twice as expensive as the standard (U–channel) delineator posts. However, where the posts were subject to numerous impacts, it is cost effective to use the flexible posts if they can survive two or more hits.

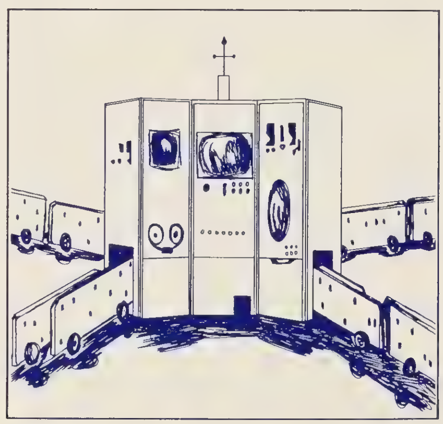
Although installing post delineators will not reduce the number of run-off-the-road accidents under all conditions, the data collected do indicate a trend toward reducing this type of accident.

The report may be purchased from NTIS.

Handbook of Computer Models for Traffic Operations Analysis, Final Report and Technical Appendix, Report Nos. FHWA–TS–82–213 and –214

by Office of Implementation

These handbooks were developed to inform practicing traffic engineers of computer models available for evaluating day-to-day transportation management problems. The final report provides a general explanation of computer modeling concepts and discusses some practical considerations in selecting computer models for traffic analysis in urban areas. Ten of the more practical computer models are described and discussed in terms of model use, input requirements, significant computational algorithms, output reports, and example applications.



The technical appendix presents a synopsis of over 100 computer models for traffic operations analysis that were identified during a literature survey. The models have been grouped for presentation based on the geometric configurations they were designed to model, for example, intersections, arterials, arterial networks, freeways, and transportation corridors. The synopsis includes a brief description of model purpose, modeling approach, programing language and structure, model application, and input and output characteristics. An annotated bibliography of references cited is included in the appendix.

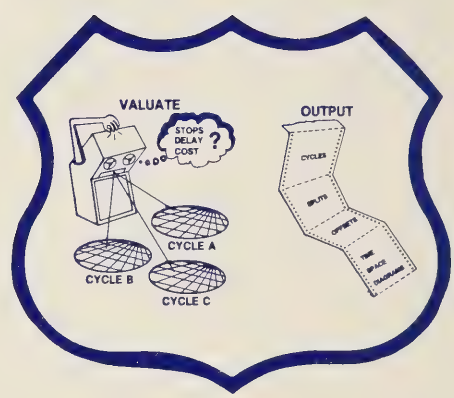
Limited copies of the handbooks are available from the Office of Implementation.

SIGOP–III, Users Manual, Implementation Package FHWA–IP–82–19

by Office of Implementation

The SIGOP–III computer program, the third version of the SIGnal OPtimization offline program, is designed to provide optimal cycle-based traffic signal timing patterns for both arterial and grid networks. The program not only optimizes splits and offsets, but also will select the optimum cycle length within a specified range. In addition to the typical measures of effectiveness associated with traffic flow, estimates of fuel consumption and vehicle emissions are provided.

The report and a loan copy of the SIGOP–III program tape are available from the Office of Implementation.



New Research in Progress

The following new research studies reported by FHWA's Offices of Research, Development, and Technology are sponsored in whole or in part with Federal highway funds. For further details on a particular study, please note the kind of study at the end of each description and contact the following: Staff and administrative contract research—*Public Roads* magazine; Highway Planning and Research (HP&R)—performing State highway or transportation department; National Cooperative Highway Research Program (NCHRP)—Program Director, National Cooperative Highway Research Program, Transportation Research Board, 2101 Constitution Avenue, NW., Washington, D.C. 20418

FCP Category 1—Improved Highway Design and Operation for Safety

FCP Project 1N: Safety of Pedestrians, Moped Operators, and Bicyclists

Title: Warrants for Pedestrian Over- and Underpasses. (FCP No. 31N1032)
Objective: Develop warrants for pedestrian over- and underpasses. Investigate the state of the art. Validate the developed warrants on a group of existing over- and underpass crossing structures. Examine the cost effectiveness and the potential for use by able-bodied pedestrians (including school-age children), handicapped pedestrians, and bicyclists.
Performing Organization: Technology Applications, Inc., Falls Church, Va. 22041
Expected Completion Date: June 1984
Estimated Cost: $72,460 (FHWA Administrative Contract)

FCP Project 1P: Visual Guidance for Night Driving

Title: Flexible Delineator Post Durability Study. (FCP No. 31P9994)
Objective: Develop a simple testing procedure for assessing the durability of flexible delineator posts and perform durability tests on all commercially available flexible delineator posts.
Performing Organization: Mobility Systems and Equipment Company, Los Angeles, Calif. 90045
Expected Completion Date: June 1984
Estimated Cost: $84,900 (FHWA Administrative Contract)

FCP Project 1R: Speed Zoning and Control

Title: Methods for Reducing Large Speed Differences in Traffic Streams. (FCP No. 31R2012)
Objective: Study methods that could reduce large differences in travel speeds and increase voluntary compliance with speed limits. Assess whether the methods can be adapted at acceptable costs. Estimate maintenance and enforcement costs/savings as well as safety and other benefits. Examine associated technical, political, legal, and enforcement issues.
Performing Organization: Martin Parker and Associates, Canton, Mich. 48187
Expected Completion Date: October 1984
Estimated Cost: $89,650 (FHWA Administrative Contract)

FCP Project 1S: Cost-Effective Geometric Design for Changing Vehicles and Limited Resources

Title: Development of Value Criteria for Highway System Cost Effectiveness. (FCP No. 31S3012)
Objective: Develop a methodology for assessing the relative values (based on costs, benefits, and effectiveness of a countermeasure) to meet a particular safety or mobility goal.
Performing Organization: The Granville Corporation, Washington, D.C. 20005
Expected Completion Date: August 1984
Estimated Cost: $89,470 (FHWA Administrative Contract)

FCP Project 1T: Advanced Vehicle Protection Systems

Title: Design Competition for Innovative Safe Terminals at Guardrail Ends. (FCP No. 31T6144)
Objective: Phase I: Develop conceptual design and preliminary analysis of innovative safe terminal at guardrail ends. Formulate potential available problem solutions. Phase II: Develop final design, and test winning innovative designs.
Performing Organization: ENSCO, Inc., Springfield, Va. 22151
Expected Completion Date: June 1984
Estimated Cost: $169,240 (FHWA Administrative Contract)

FCP Project 1V: Roadside Safety Hardware for Nonfreeway Facilities

Title: Rollover Potential of Vehicles on Embankments, Sideslopes, and Other Roadside Features. (FCP No. 31V1052)
Objective: Examine the critical effect of roadside features on vehicle rollover. Study small, modern automobiles and utility type vehicles as well as larger vehicles comprising a significant part of the vehicle population. Examine the interaction of roadside features and vehicular structural and design characteristics.
Performing Organization: Calspan Field Services, Inc., Buffalo, N.Y. 14225
Expected Completion Date: December 1985
Estimated Cost: $358,270 (FHWA Administrative Contract)

Title: Guardrail-Bridge Rail Transition Designs. (FCP No. 31V3092)
Objective: Develop design guidelines for transitions and approach guardrails. Test and evaluate current transition designs. Design, test, and develop transitions and approach guardrail systems that can be used for safety treatment or upgrading of old bridges.
Performing Organization: Southwest Research Institute, San Antonio, Tex. 78284
Expected Completion Date: September 1985
Estimated Cost: $297,500 (FHWA Administrative Contract)

Title: Median Barrier Terminals and Median Treatments. (FCP No. 31V3352)
Objective: Identify specific problems associated with median barrier terminal and median treatment solutions. Redesign an existing terminal or develop a new terminal to solve specific deficiencies. Address problems peculiar to medium and wide medians and bridge piers. Perform full-scale crash tests on new designs.
Performing Organization: Southwest Research Institute, San Antonio, Tex. 78284
Expected Completion Date: February 1986
Estimated Cost: $273,500 (FHWA Administrative Contract)

FCP Project 1X: Highway Safety Program Effectiveness Evaluation

Title: Cost-Effective Inventory Procedures for Highway Data. (FCP No. 31X1113)
Objective: Collect information on the current practices and state of the art for inventorying roadway and roadside elements. Conduct a cost-effective comparison of the identified inventory procedures or combinations of procedures. Prepare recommendations for the selection of an inventory procedure(s).
Performing Organization: Goodell-Grivas, Inc., Southfield, Mich. 48075
Expected Completion Date: July 1984
Estimated Cost: $57,600 (FHWA Administrative Contract)

Title: Validation of Nonaccident Variables as Safety Measures. (FCP No. 31X2122)
Objective: Quantify the relationship between selected surrogate measures and accident experience for specific highway conditions at rural isolated horizontal curves and rural signalized intersections.
Performing Organization: Arvin/Calspan, Buffalo, N.Y. 14225
Expected Completion Date: July 1985
Estimated Cost: $182,900 (FHWA Administrative Contract)

FCP Category 2—Reduction of Traffic Congestion and Improved Operational Efficiency

FCP Project 2L: Detection and Communications for Traffic Systems

Title: Concepts for a Low-Cost Motorist Information System. (FCP No. 32L3082)
Objective: Provide a concept for a practical but low-cost system that will provide motorists with timely, specific, credible information on road conditions, incidents, motorist services, and traffic conditions for intended routes. Develop a means for consolidating and disseminating the information (for example, by car radios).
Performing Organization: JHK and Associates, Inc., Alexandria, Va. 22304
Expected Completion Date: August 1984
Estimated Cost: $163,900 (FHWA Administrative Contract)

FCP Project 2P: Improved Utilization of Available Freeway Lanes

Title: Weaving Analysis Procedures for the New Highway Capacity Manual. (FCP No. 32P1092)
Objective: Evaluate the Piny and Leisch weaving analysis procedures for accuracy, ease of application, and compatibility with the overall freeway material scheduled to be incorporated into the new Highway Capacity Manual. Modify the procedures as necessary and make recommendations concerning their use.
Performing Organization: JHK and Associates, Inc., Emeryville, Calif. 94608
Expected Completion Date: July 1984
Estimated Cost: $102,700 (FHWA Administrative Contract)

FCP Category 4—Improved Materials Utilization and Durability

FCP Project 4B: Design and Rehabilitation of Rigid Pavements

Title: An Evaluation of Concrete Pavement Using Nondestructive Testing Techniques. (FCP No. 44B2012)
Objective: Phase I: Purchase a falling weight deflectometer and develop standard testing and evaluation techniques and data reduction and analysis programs. Phase II: Select reasonable rehabilitation options. Phase III: Compile a design package to evaluate the added pavement life that various rehabilitation methods or combination of methods would provide to select the most cost-effective option.
Performing Organization: University of Illinois, Urbana, Ill. 61801
Funding Agency: Illinois Department of Transportation
Expected Completion Date: June 1987
Estimated Cost: $219,100 (HP&R)

FCP Project 4C: Design and Rehabilitation of Flexible Pavements

Title: Effectiveness of Rubberized Asphalt in Stopping Reflection Cracking of Asphalt Concrete. (FCP No. 44C4034)
Objective: Evaluate 13 different sections on their effectiveness in controlling reflective cracking. Collect information on aerial and closeup photographs, detailed crack counts, after-construction cores, temperature, rainfall, and annual traffic counts.
Performing Organization: California Department of Transportation, Sacramento, Calif. 95809
Expected Completion Date: June 1987
Estimated Cost: $54,000 (HP&R)

FCP Project 4D: Remedial Treatment of Soil Materials for Earth Structures

Title: Asphalt Characterization and Performance Study. (FCP No. 44D1062)
Objective: Develop the capability of using tests of chemical composition to characterize liquid asphalts using high-pressure liquid chromatography. Determine the relationship between liquid asphalt composition from test sections of selected inservice asphalt pavements. Determine the effects on stripping of adding hydrated lime and other admixtures to the liquid asphalt. Review liquid asphalt specifications to determine if they are providing a product that produces durable asphalt pavements at an economical price.
Performing Organization: Georgia Department of Transportation, Atlanta, Ga. 30334
Expected Completion Date: June 1986
Estimated Cost: $150,140 (HP&R)

FCP Category 5—Improved Design to Reduce Costs, Extend Life Expectancy, and Insure Structural Safety

FCP Project 5A: Improved Protection Against Natural Hazards of Earthquake and Wind

Title: Bridge Response to Turbulent Wind Loading—Deer Isle Suspension Bridge, Maine. (FCP No. 35A2112)
Objective: Establish detailed turbulent and fluctuating characteristics of natural wind environment at the Deer Isle-Sedgwick Suspension Bridge. Characterize motion of the bridge in response to various wind conditions. Develop wind spectra, structural mode shapes, frequencies, and damping estimates.
Performing Organization: Battelle Memorial Institute, Richland, Wash. 99352
Expected Completion Date: December 1985
Estimated Cost: $135,000 (FHWA Administrative Contract)

Title: Effects of Scaled Turbulence on Bridge Flutter and Buffeting Theory. (FCP No. 35A2132)
Objective: Determine the effects of introducing two-dimensional, scaled turbulence into the experimental and analytical schemes for evaluating suspended bridge dynamic response to various wind environments. Develop new or modified laboratory methods and computer software. Conduct laboratory tests to evaluate the new procedures. Use test results to evaluate structural response to turbulent wind loadings.
Performing Organization: Colorado State University, Fort Collins, Colo. 80523
Expected Completion Date: January 1986
Estimated Cost: $182,000 (FHWA Administrative Contract)

Title: Waveform Analysis of Aerodynamic Data. (FCP No. 35A2142)
Objective: Review two large computer program libraries used for waveform analysis of aerodynamic data. Consolidate programs and develop new programs where necessary. Implement enhanced program libraries and test on FHWA computers. Develop revised documentation.
Performing Organization: University of Arizona, Tucson, Ariz. 85721
Expected Completion Date: April 1985
Estimated Cost: $70,500 (FHWA Administrative Contract)

Title: Development of Cost-Effective Bridge Systems—Part II. (FCP No. 45A3512)
Objective: Phase I addressed conceptual questions on the development of cost-effective bridge systems. In Phase II, develop lists of viable bridge types and lengths and develop logic tables and interactive computer programs for use by designers.
Performing Organization: Pennsylvania State University, University Park, Pa. 16802
Funding Agency: Pennsylvania Department of Transportation
Expected Completion Date: August 1985
Estimated Cost: $74,000 (HP&R)

Title: Development of Reinforcement in Concrete Made Using Superplasticizers. (FCP No. 45A3532)
Objective: Conduct analytical and laboratory studies of the anchorage and development of reinforcement in concrete made using superplasticizers.
Performing Organization: University of Texas, Austin, Tex. 78712
Funding Agency: Texas State Department of Highways and Public Transportation
Expected Completion Date: August 1985
Estimated Cost: $50,000 (HP&R)

FCP Project 5K: New Bridge Design Concepts

Title: Special Problems of Metal Bridges. (FCP No. 45K1192)
Objective: Perform nondestructive field tests on 10 to 15 bridges in Kentucky. Develop procedures to economically perform nondestructive surveillance.
Performing Organization: University of Kentucky, Lexington, Ky. 40506
Funding Agency: Kentucky Department of Transportation
Expected Completion Date: July 1986
Estimated Cost: $87,500 (HP&R)

Title: Design of Multibeam Precast Bridge Superstructures. (FCP No. 55K2042)
Objective: Develop criteria for the design of connections between adjacent precast elements in multibeam bridge superstructures and specification provisions for the lateral distribution of wheel loads in precast multibeam bridge superstructures of single-, double-, and multiple-stem tee girders.
Performing Organization: University of Washington, Seattle, Wash. 98195
Expected Completion Date: June 1985
Estimated Cost: $150,000 (NCHRP)

Title: Criteria for Designing Lightweight Concrete Bridges. (FCP No. 35K2072)
Objective: Collect and evaluate existing information on the material and structural properties of lightweight aggregate concrete including its limitations. Prepare a report that will provide guidance to potential users of the material in the design, construction, or rehabilitation of highway bridges. Emphasize structural applications of prestressed lightweight concrete.
Performing Organization: T. Y. Lin International, San Francisco, Calif. 94133
Expected Completion Date: February 1985
Estimated Cost: $117,890 (FHWA Administrative Contract)

FCP Category 0—Other New Studies

Title: Production of Concrete Containing Fly Ash. (FCP No. 40M3803)
Objective: Establish guidelines for selecting materials and trial mix design procedures for producing good quality concrete containing fly ash. Identify most relevant properties of fly ash affecting fresh and hardened concrete. Conduct laboratory tests for freeze-thaw resistance, sulfate resistance, abrasion, shrinkage, chloride susceptibility, and wear of concrete containing fly ash. Conduct pilot studies to evaluate performance in the field and incorporate findings into guidelines and specifications.
Performing Organization: University of Texas, Austin, Tex. 78712
Funding Agency: Texas State Department of Highways and Public Transportation
Expected Completion Date: August 1986
Estimated Cost: $65,000 (HP&R)

☆U.S. Government Printing Office: 1983—421–783/301

RD&T Outstanding Paper Awards Presented

Dr. Brian H. Chollar, Dr. Bernard R. Appleman, and Mr. Milton K. Mills were the recipients of the 1983 awards in the annual outstanding technical achievement competition held among the employees of the Federal Highway Administration (FHWA) Offices of Research, Development, and Technology (RD&T). This award covers the documentation of any technical accomplishment, which may be a publication, technical paper, report, or package; an innovative engineering concept; an instrumentation system; test procedure; new specification; mathematical model; or unique computer program. Each eligible candidate is judged on excellence, creativity, and contribution to the highway community, general public, and FHWA.

Dr. Chollar, a research chemist in the Materials Technology and Chemistry Division, Office of Engineering and Highway Operations Research and Development (R&D), and Dr. Appleman, a research chemist formerly in the Offices of Research and Development and presently with Exxon Research and Engineering, received awards for their research paper "Epoxy Thermoplastic Marking Material: Revised Specification." The paper presents the results of an extensive in-house laboratory program to establish a specification for purchasing and using epoxy thermoplastic (ETP) pavement marking material. The specification provides generic rather than proprietary descriptions of the components of white and yellow ETP's. Statistical procedures were used to establish confidence limits for the repeatability and reproducibility of the test procedures used in the specification.

Mr. Mills, an electronics engineer in the Systems Technology Division, Office of Safety and Traffic Operations R&D, received an award for his research paper "Inductive Loop Detector Analysis," the only known published quantitative analysis of the effects of reinforcing steel in concrete pavement on the sensitivity of inductive loop vehicle detectors. The paper includes an analysis of the effect of pavement loss tangent (a function of moisture content) on loop electrical parameters and shows the optimum value of "quality factor," which is proportional to operational frequency. Results from this paper have been incorporated into FHWA's Vehicle Detector Handbook.

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